CERES Ed4 Cloud Properties

P. Minnis, D. Doelling (calibration), W. L. Smith (offline val)

NASA Langley Research Center, Hampton, VA, USA

S. Sun-Mack (QB), Q. Trepte (mask), F-L. Chang (CO2, ML),
T. Chee (web, DM), R. Arduini (RTM), K. Bedka (OT tops),
S. Bedka (SIST), R. Brown (QC), Y. Chen (clr props, test runs),
S. Gibson (graphics), E. Heckert (web, IG), G. Hong (night tau), M. Khaiyer (val), R. Palikonda (offline testing), R. Smith (web, NPP),
D. Spangenberg (polar), Y. Yi (thickness), C. Yost (phase)

SSAI, Hampton, VA, USA

P. W. Heck (retrieval algo)

CIMSS, U. Wisconsin, Madison, Wi, USA

P. Yang, Y. Xie (ice cloud models)

Texas A&M Univ., College Station, TX, USA

Update of CERES Cloud-related Papers, etc.

Edition-2 related

Chepfer, H., S. Bony, D. Winker, G. Cesana, J. L. Dufresne, P. Minnis, C. J. Steubenrauch, and S. Zeng, 2010: The GCM Oriented CALIPSO Cloud Product (CALIPSO-GOCCP). *J. Geophys. Res.*, **115**, D00H16, doi:10.1029/2009JD012251.

Lin, B., P. Minnis, T.-F. Fan, Y. Hu, and W. Sun, 2010: Characterizing radiative properties of low and high clouds in different oceanic cloud regions using CERES data. *Intl. J. Remote Sens.*, **31**:24, 6473-6492, doi: 10.1080/01431160903548005.

Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, R. F. Arduini, Q. Z. Trepte, W. L. Smith, Jr., J. K. Ayers, S. C. Gibson, W. F. Miller, V. Chakrapani, Y. Takano, K.-N. Liou, Y. Xie, and P. Yang, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part I: Algorithms. *IEEE Trans. Geosci. Remote Sens.*, doi: 10.1109/TGRS. 2011.2144601, in press.

(http://www-pm.larc.nasa.gov/ceres/pub/journals/Minnis.CERES.Part.Io.pdf)

Minnis, P., S. Sun-Mack, Y. Chen, M. M. Khaiyer, Y. Yi, J. K. Ayers, R. R. Brown, X. Dong, S. C. Gibson, P. W. Heck, B. Lin, M. L. Nordeen, L. Nguyen, R. Palikonda, W. L. Smith, Jr., D. A. Spangenberg, Q. Z. Trepte, and B. Xi, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part II: Examples of average results and comparisons with other data. *IEEE Trans. Geosci. Remote Sens.*, doi: 10.1109/TGRS.2011.2144602, in press.

(http://www-pm.larc.nasa.gov/ceres/pub/journals/Minnis.CERES.part.IIo.pdf)

Update of CERES Cloud-related Papers, etc.

Edition-2 related

Wang, W., J. Huang, P. Minnis, Y. Hu, J. Li, Z. Huang, and J. K. Ayers, 2010: Dusty cloud properties and radiative forcing over dust source and downwind regions derived from CERES and CALIPSO data during PACDEX. *J. Geophys. Res.*, **115**, doi:10.1029/2010JD014109, D00H35.

Yan, H., J. Huang, P. Minnis, T. Wang, and J. Bi, 2011: Comparison of CERES surface radiation fluxes with surface observations over the Loess Plateau. *Remote. Sens. Environ.*, accepted.

Li, J. Y. Yi, P. Minnis, J. Huang, H. Yan, Y. Ma, W. Wang, and J. K. Ayers, 2011: Radiative effect differences between multi-layered and single-layer clouds derived from CERES, CALIPSO, and CloudSat data. Submitted to *J. Quant. Spectrosc. Radiat. Transfer*.

Update of CERES Cloud-related Papers, etc.

Edition-4 related

Chang, F.-L., P. Minnis, B. Lin, M. Khaiyer, R. Palikonda, and D. Spangenberg, 2010: A modified method for inferring cloud top height using GOES-12 imager 10.7- and 13.3-μm data. *J. Geophys. Res.*, **115**, D06208, doi:10.1029/2009JD012304.

Chang, F.-L., P. Minnis, J. K. Ayers, M. J. McGill, R. Palikonda, D. A. Spangenberg, W. L. Smith, Jr., and C. R. Yost, 2010: Evaluation of satellite-based upper-troposphere cloud-top height retrievals in multilayer cloud conditions during TC4. *J. Geophys. Res.*, D00J05, **115**, doi: 10.1029/2009JD012800.

Xie, Y., P. Yang, G. W. Kattawar, P. Minnis, Y. Hu, and D. Wu, 2011: Determination of ice cloud models using MODIS and MISR data. *Quart. J. Royal Meteor. Soc.*, submitted.

Chen, Y., P. Minnis, S. Sun-Mack, R. F. Arduini, and Q. Z. Trepte, 2010: Clear-sky and surface narrowband albedo datasets derived from MODIS data. *Proc. AMS 13th Conf. Atmos. Rad. and Cloud Phys.*, Portland, OR, June 27 – July 2, JP1.2.

Trepte, Q. Z., P. Minnis, C. R. Trepte, S. Sun-Mack, and R. Brown, 2010: Improved cloud detection in CERES Edition 3 algorithm and comparison with the CALIPSO Vertical Feature Mask. *Proc. AMS 13th Conf. Atmos. Rad. and Cloud Phys.*, Portland, OR, June 27 – July 2, JP1.32.

Chang, F.-L., P. Minnis, S. Sun-Mack, L. Nyugen, and Yan Chen, 2010: On the satellite determination of multi-layered multi-phase cloud properties. *Proc. AMS 13th Conf. Atmos. Rad. and Cloud Phys.*, Portland, OR, June 27 – July 2, JP1.10.

Minnis, P., S. Sun-Mack, Q. Z. Trepte, F.-L. Chang, P. W. Heck, Y. Chen, Y. Yi, R. F. Arduini, K. Ayers, K. Bedka, S. Bedka, R. Brown, S. Gibson, E. Heckert, G. Hong, Z. Jin, R. Palikonda, R. Smith, W. L. Smith, Jr., D. A. Spangenberg, P. Yang, C. R. Yost, and Y. Xie, 2010: CERES Edition 3 cloud retrievals. *AMS 13th Conf. Atmos. Rad.*, Portland, OR, June 27 – July 2, 5.4.

CERES-Developed MODIS Calibration Corrections

in current Ed 4 **not in current Ed 4** **not in current Ed4**
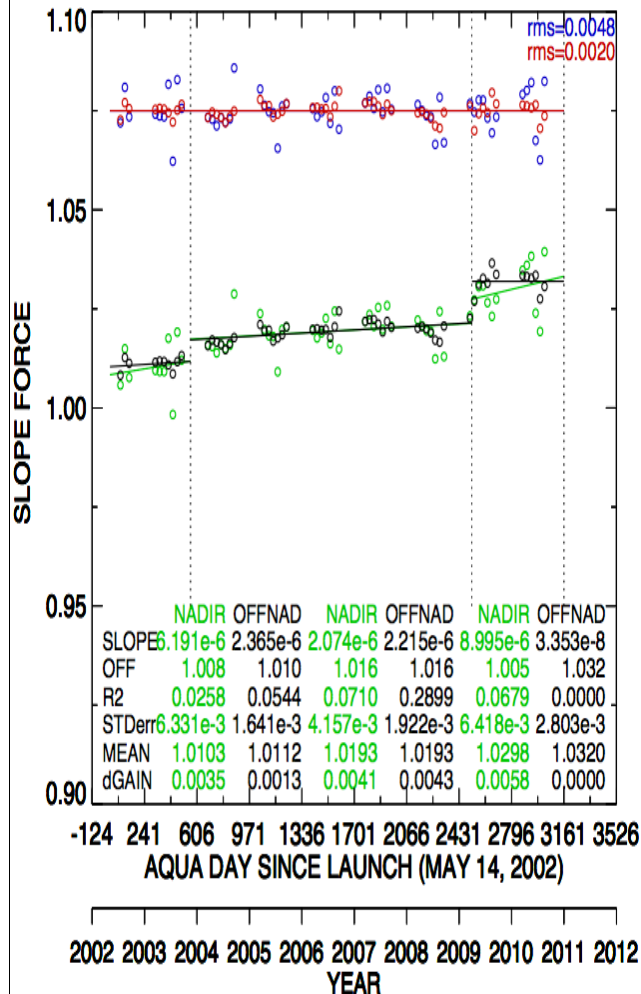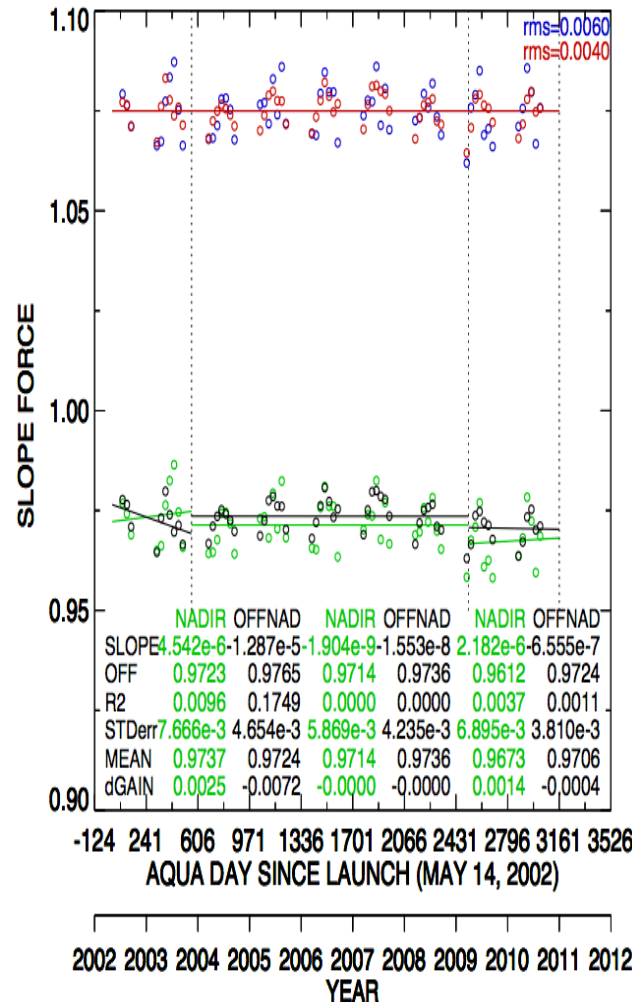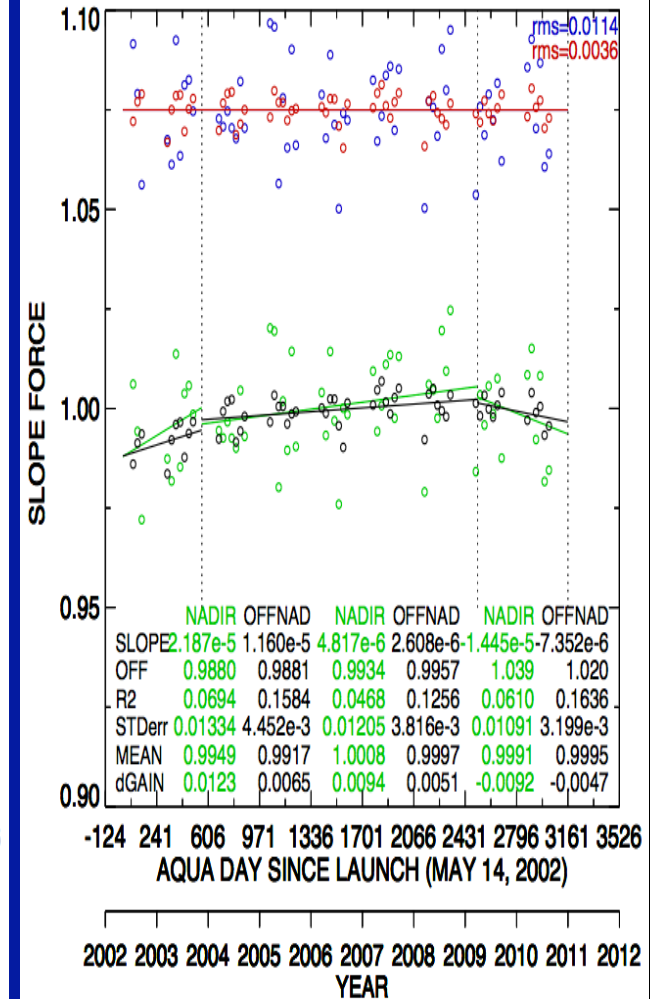
Cal differences affect optical depth, Re/re, cloud fraction

Ed4 Clouds

All results shown here use the code delivered in February but run offline while the code conversion and testing at ASDC continue

CERES Cloud Mask Changes Since Last STM

In framework that impacts final mask

- Terra $T_{3.75}$ new calibration, towards Aqua $T_{3.75}$
- Terra Ref $_{0.65}$ correction, towards Aqua Ref $_{0.65}$
- CO_2 slicing cloudy overwrite mask clear and ratio 1.24/0.65 tests overwrite mask cloudy

Daytime non-polar, improved

- clear Sun glint detection after all B cloudy
- clouds in Sun glint detection after all B clear
- clouds, aerosol, and glint detection in 6 C tests
- dust / low cloud discrimination (added ratio 1.24/0.65)
- thin Ci detection over ocean and land
- coastal clouds detection

Nighttime non-polar

- Improved thin Ci and low clouds detection
- Increased clouds detection over ocean
- Increased desert cloud detection. Dropped 3.75-11 CS STD from 2 to 1.5K

CERES Cloud Mask Changes Since Last STM - 2

Daytime Polar

- Improved ice clouds, snow surface, clear land, thin Ci detection, (added ref1.38)
- Added clear_snow overwrite clear_good and clear_weak using snow, ice, IGBP maps and spectral tests

Nighttime Polar

- Improved normal clouds and inversion clouds detection
- Changed the cloud tests over super cold plateau (Antarctica and Greenland)
- Improved the classification of TBD pixels
- Added clear sky restoral tests

Comparison of Cloud Fraction between Ed4 and CALIPSO V3 VFM

2008 Fall SON Day

2008 FALL SON Night

Aqua Ed4

TerraEd4

CALIPO V3 Filtered out horizontal averaging 80 km required for detection

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
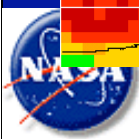
Aqua Ed4 and CALIPSO V3 VFM, 2008 Summer JJA

Filtered out 20 & 80 km horizontal averaging required for detection

Filtered out horizontal averaging 80 km for detection

Aqua Ed4

CALIPSO V3

Day

Night

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
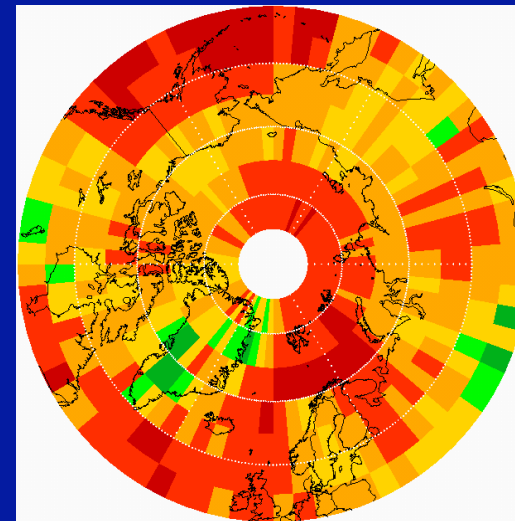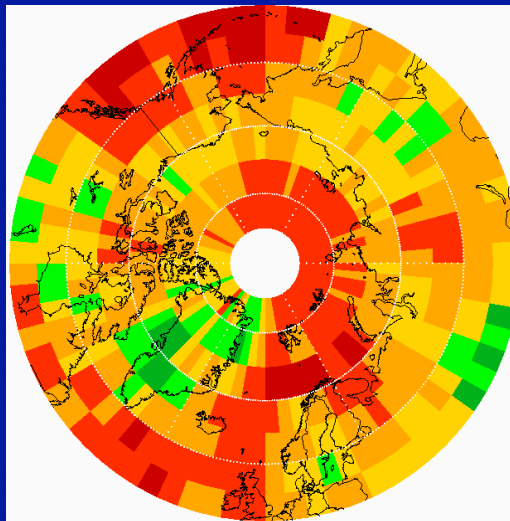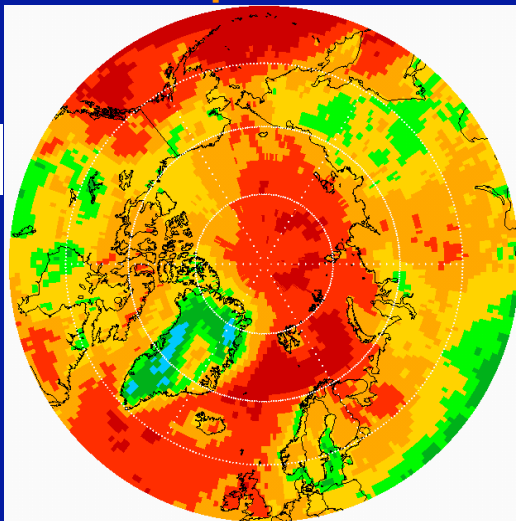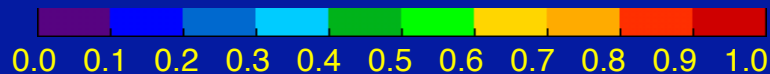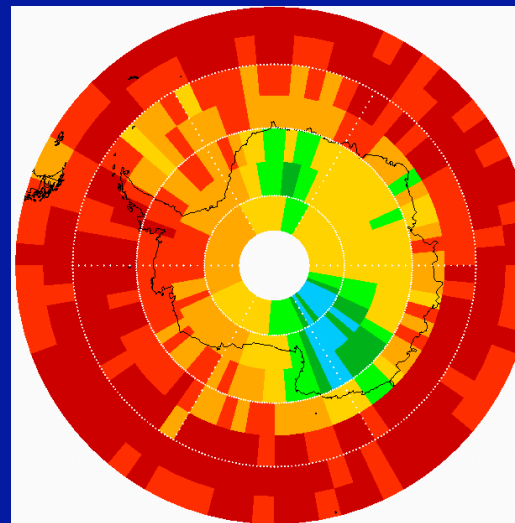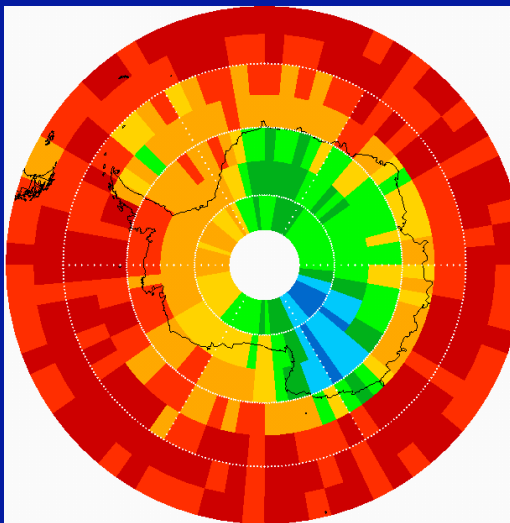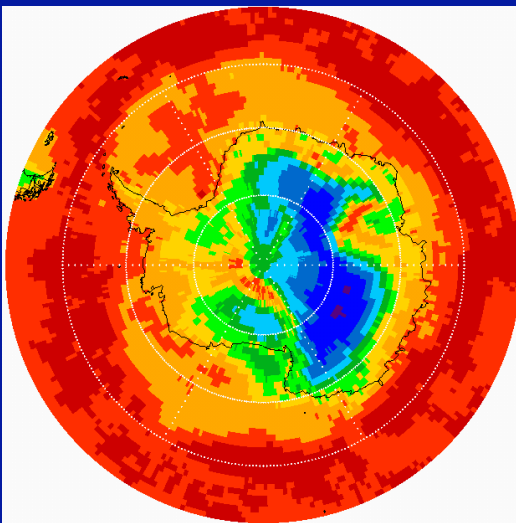
Aqua Ed4 and CALIPSO V3 VFM, 2008 Winter JFD

Filtered out 20 & 80 km horizontal averaging required for detection

Filtered out horizontal averaging 80 km for detection

Aqua Ed4

CALIPSO V3

Day
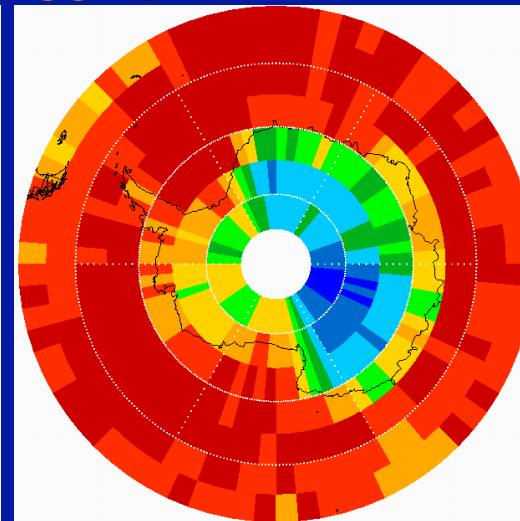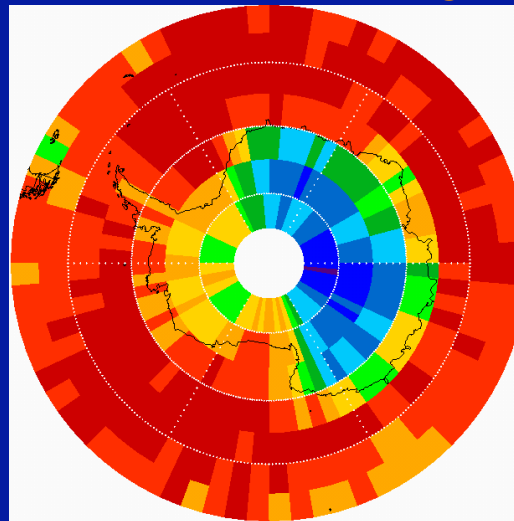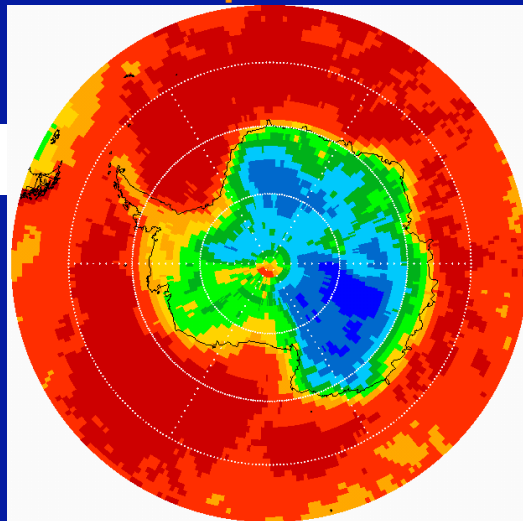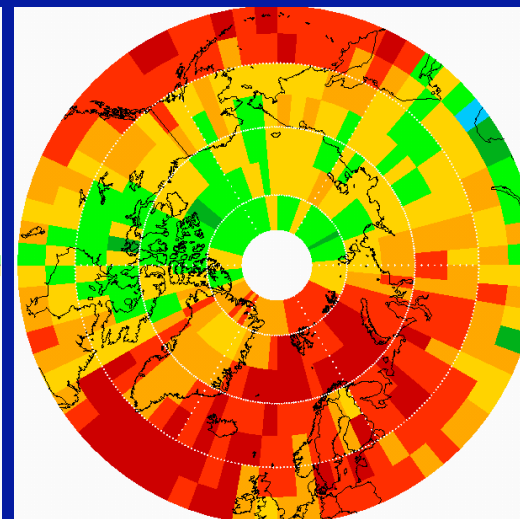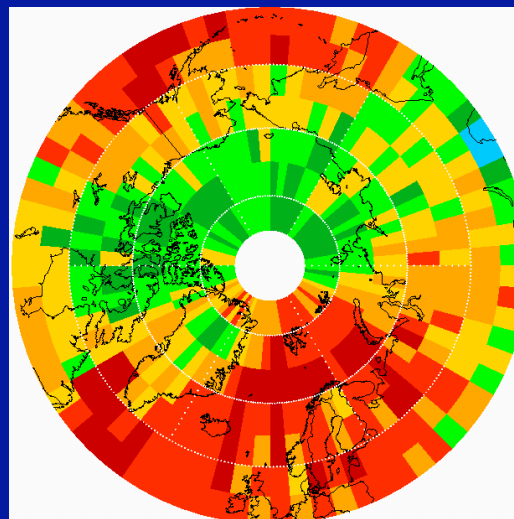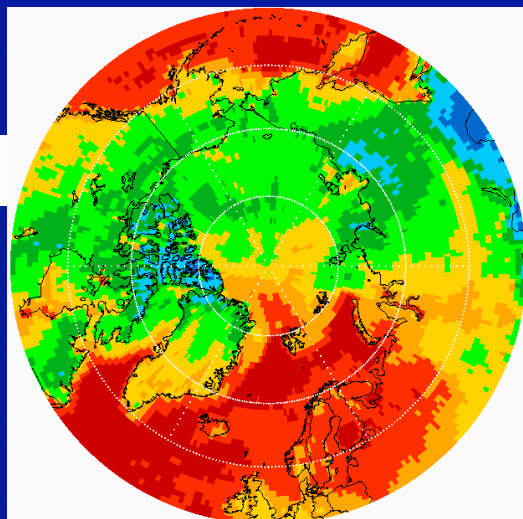
Night

CERES Ed4 is closer to CALIPSO filter out 20 & 80 km

0.0 0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1.0
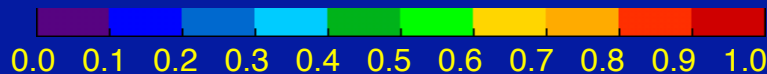
Zonal Cloud Fraction between Aqua Ed4 and CALIPSO V3 with different filters

Day

Night

2008 Summer

2008 Winter

Cloud Fraction

Latitudes

- CAL_All
- CERES_Aqua Ed4
- CAL_filtered 20&80km
- CAL_filtered 80km
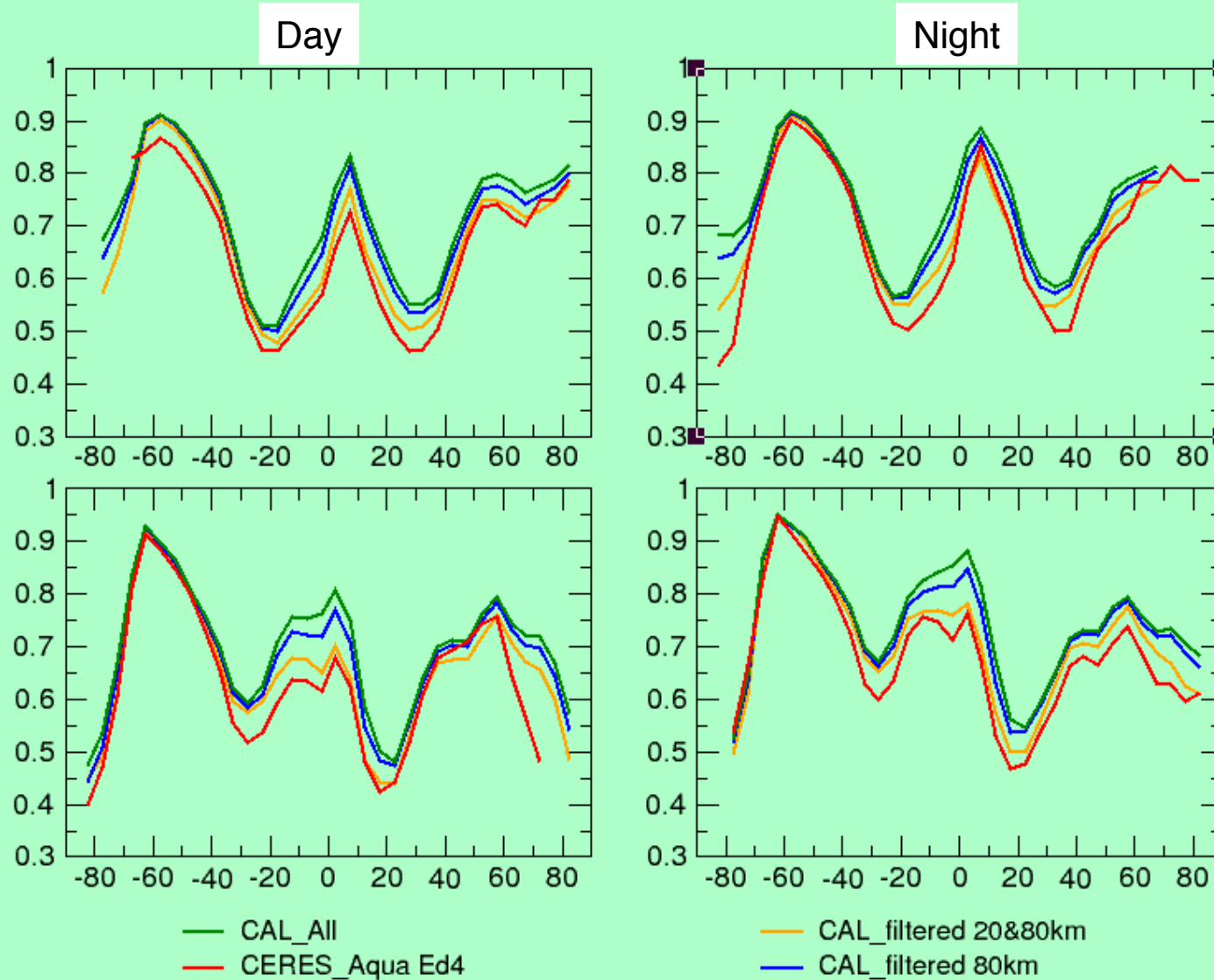
Seasonal Zonal Cloud Fraction between Aqua Ed4 and CALIPSO V3
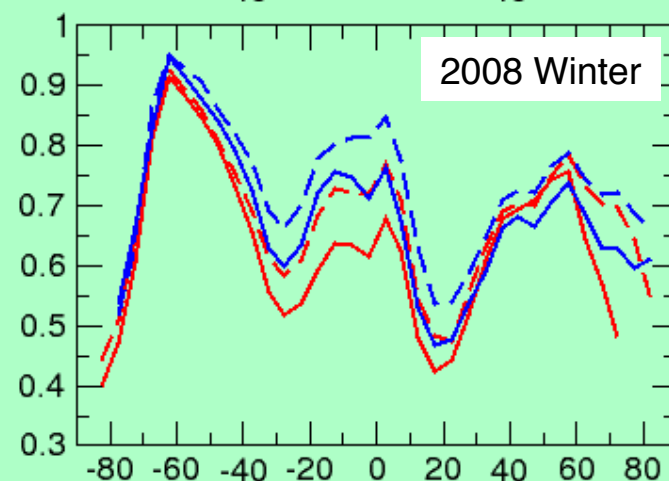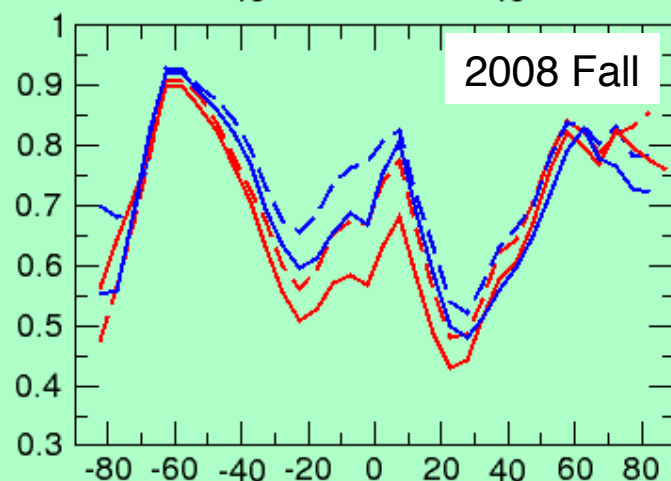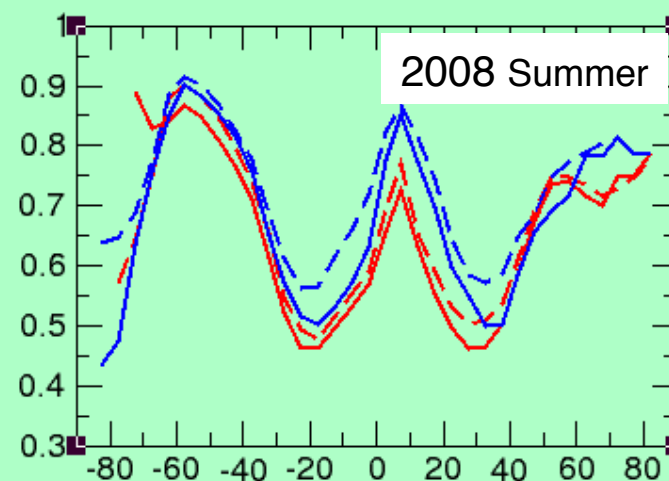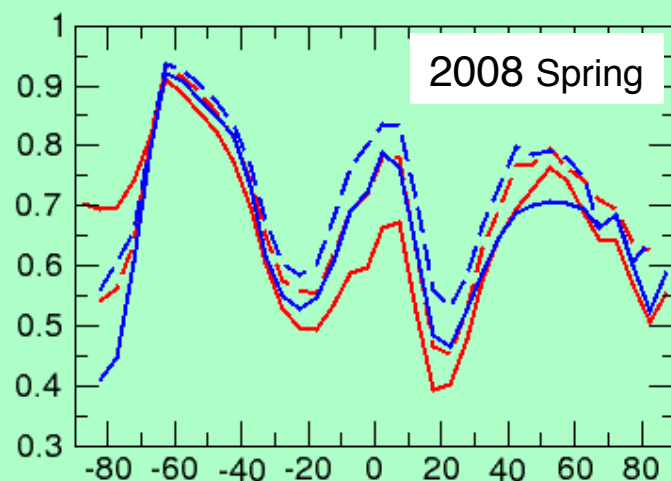
Cloud Fraction, Aqua 2008, Day Time, Ocean
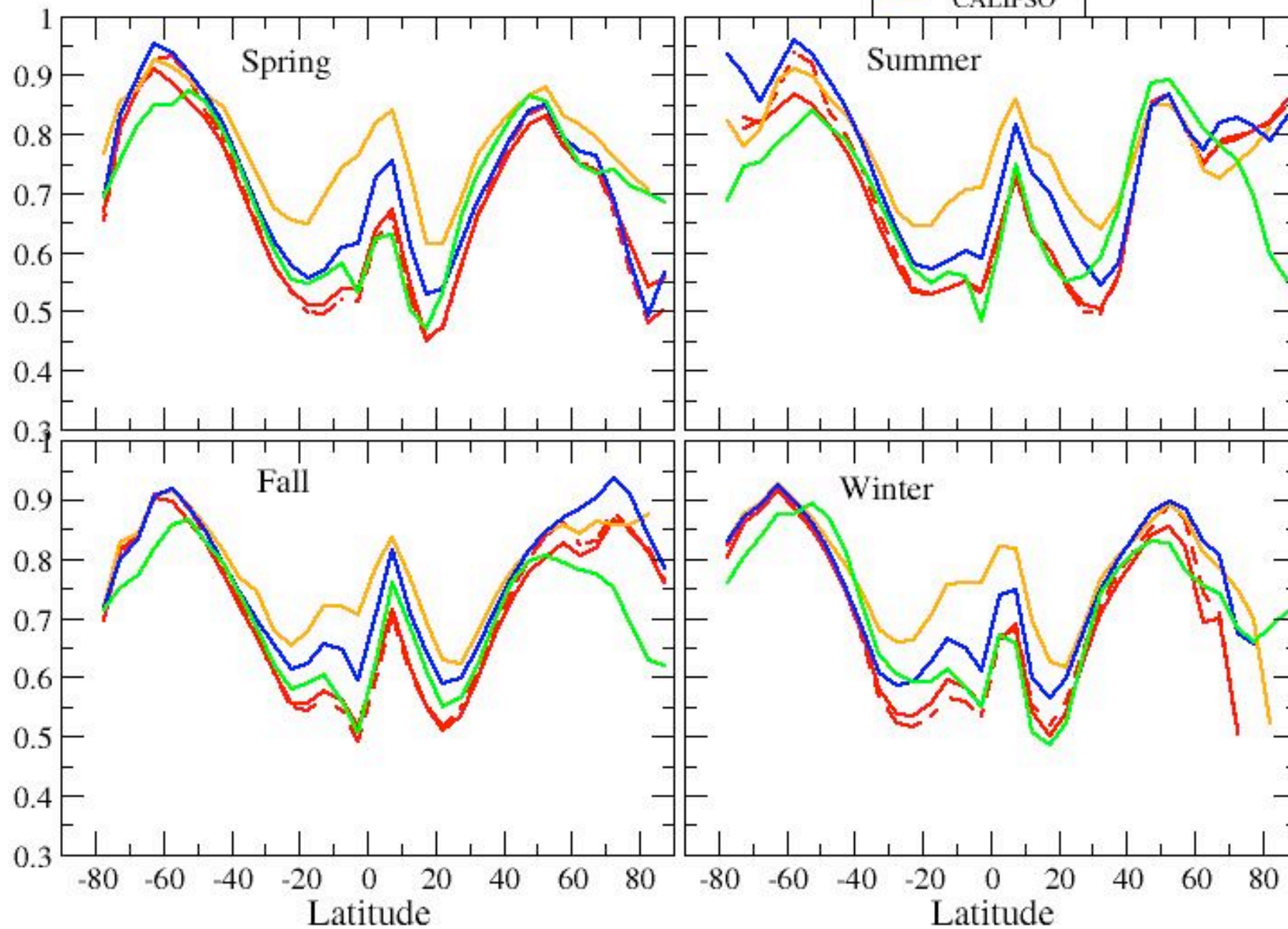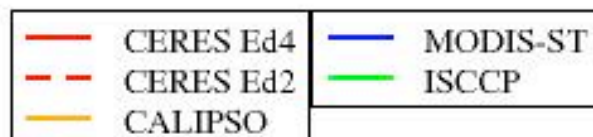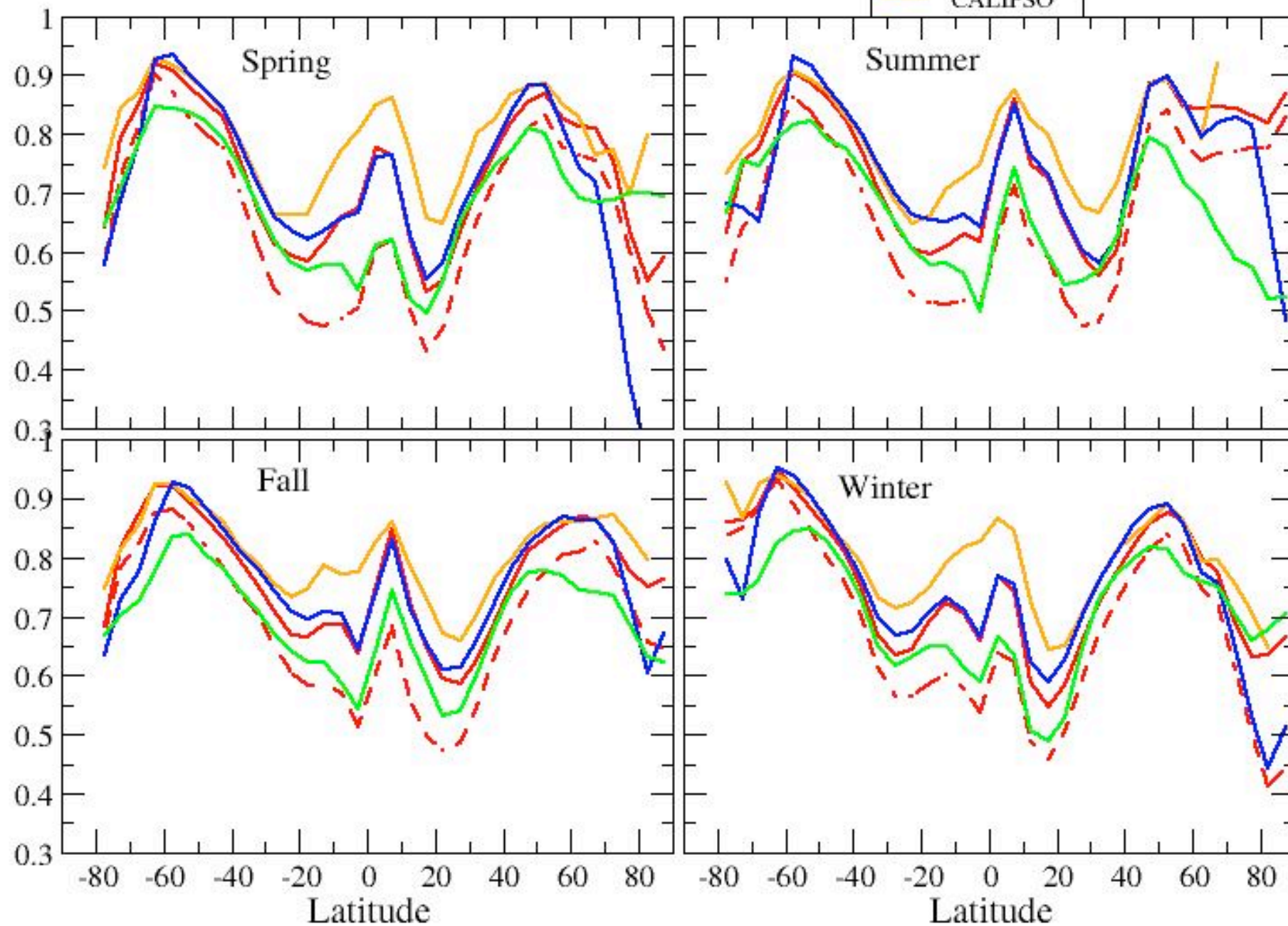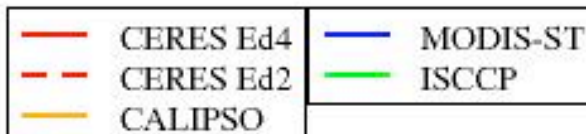
Cloud Fraction, Aqua 2008, Day Time, Land
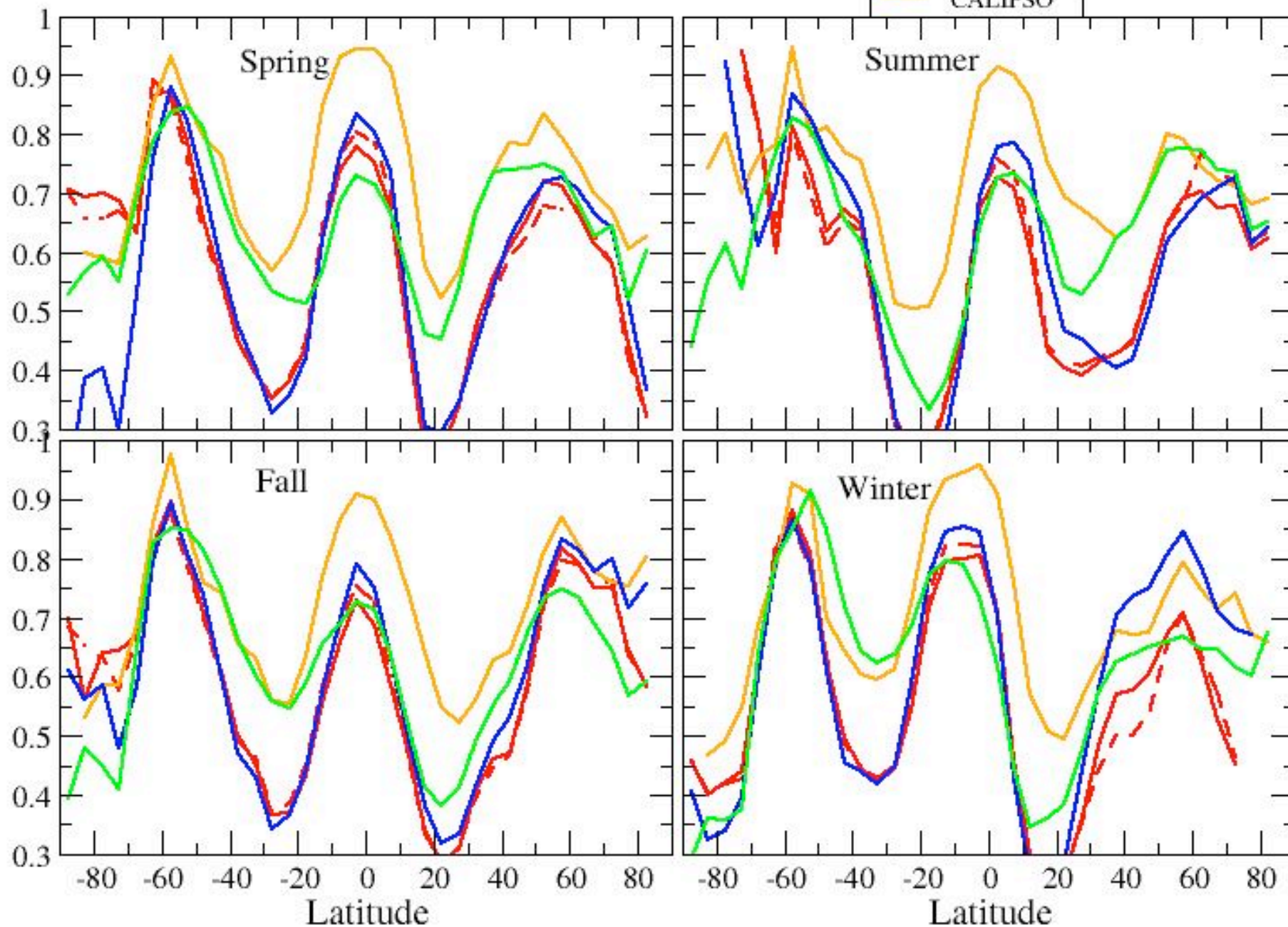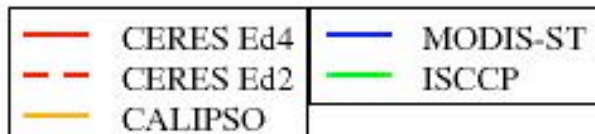
Cloud Fraction, Aqua 2008, Night Time, Land
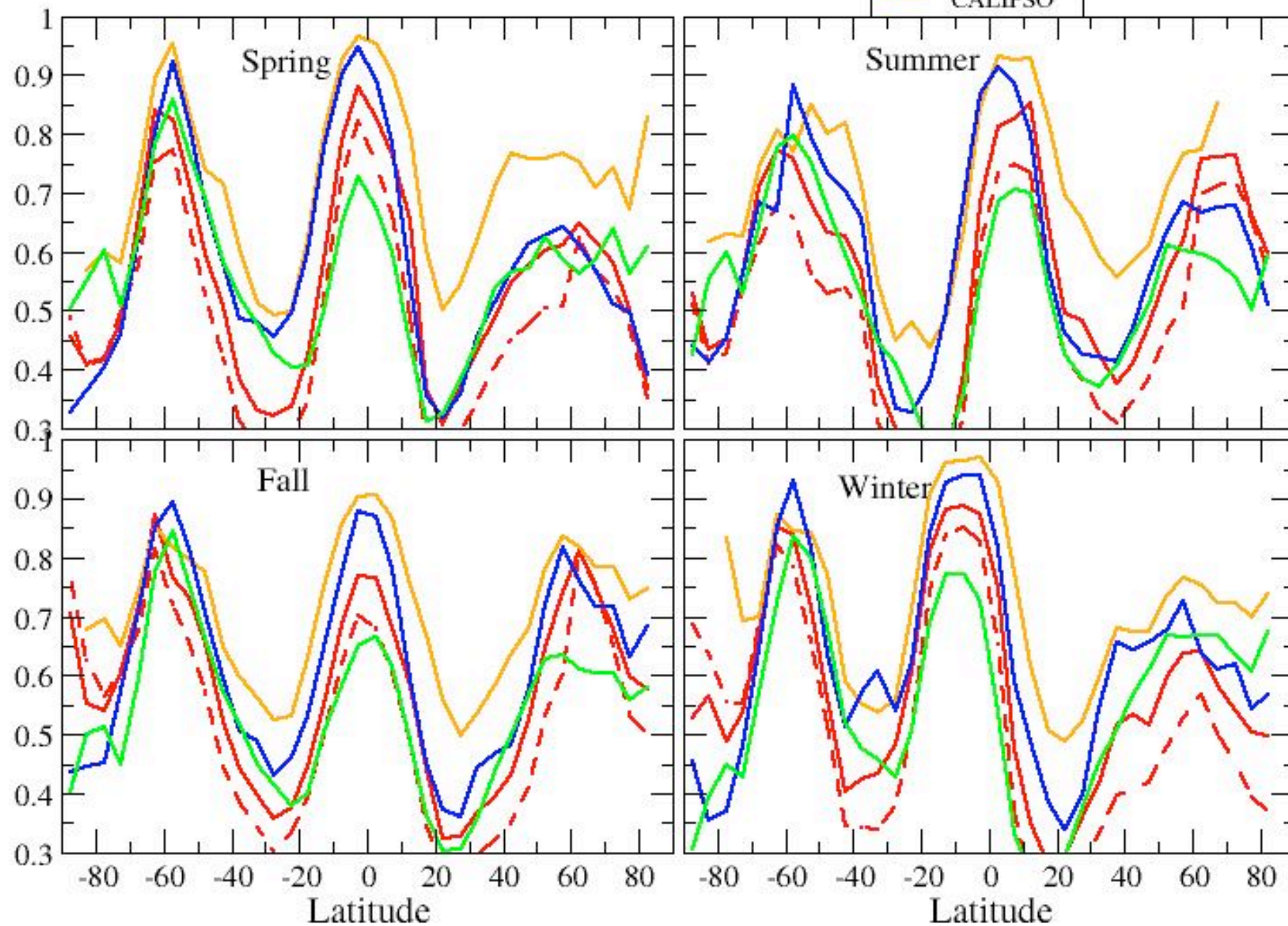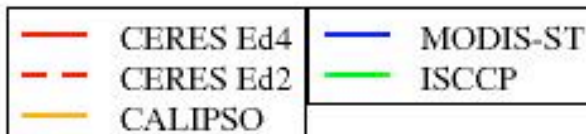
Cloud Fraction, Aqua 2008, Night Time, Ocean
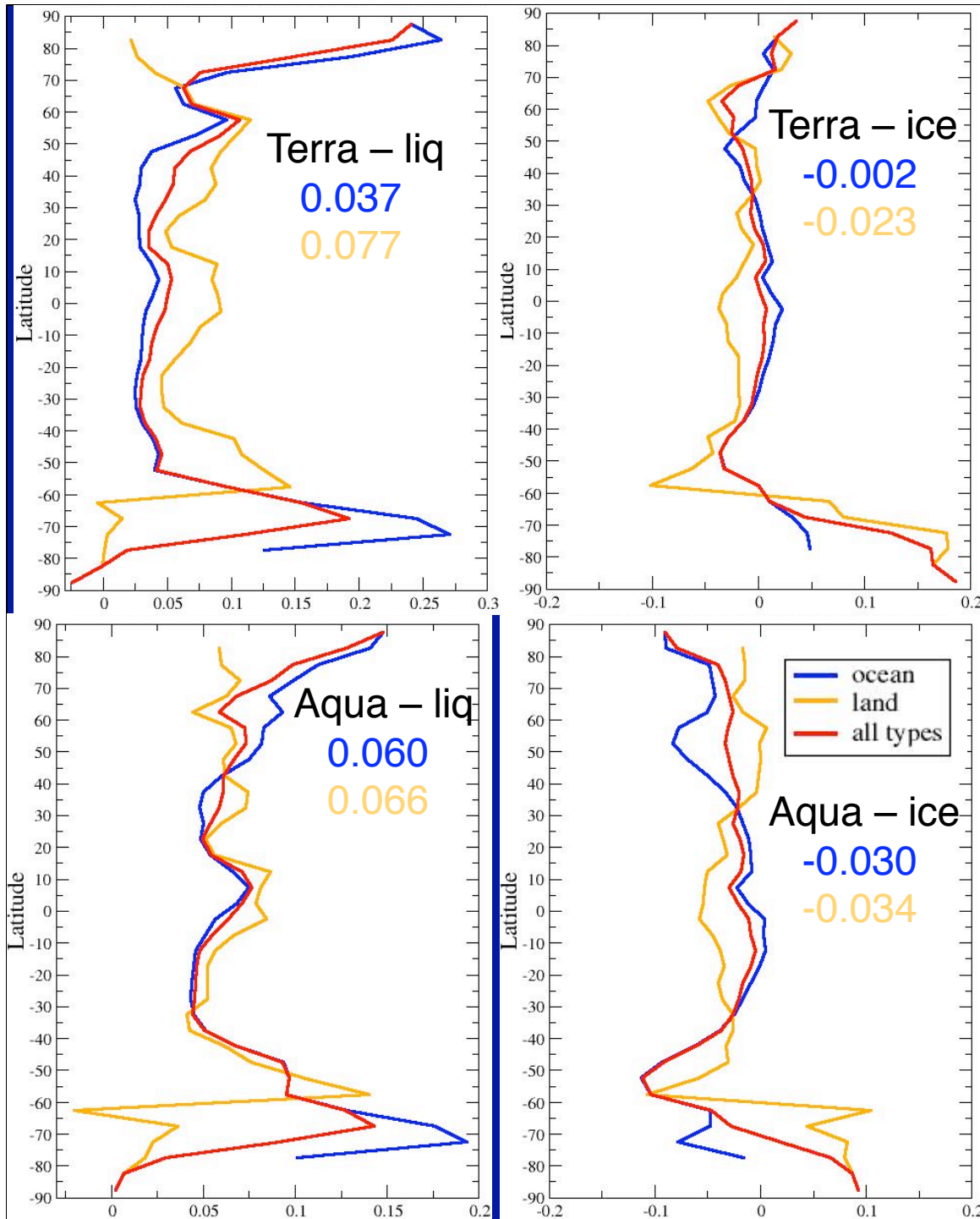
Ed4-Ed2 Differences
Cloud Fraction, 2008

Daytime
Averages shown are
for 60N-60S

• Liquid cloud increase
  - *greatest over land & polar*

• decrease in ice clouds
  - *larger for Aqua*
    - *1.2/vis ratio check?*
  - *worse for land*

Terra – liq
0.037
0.077

Terra – ice
-0.002
-0.023

Aqua – liq
0.060
0.066

Aqua – ice
-0.030
-0.034

ocean
land
all types

Seasonal Global Cloud Fraction Comparison 2008

Day   **Night**

	Terra Ed4	Aqua Ed4	CAL 80km	CAL 20&80 km	Terra Ed4	Aqua Ed4	CAL 80km	CAL 20&80 km
Spring	0.62	0.63	0.69		0.65	0.66	0.72	
Summer	0.62	0.62	0.70	0.67	0.66	0.67	0.72	0.69
Fall	0.63	0.64	0.70		0.68	0.69	0.75	
Winter	0.63	0.63	0.68	0.65	0.67	0.68	0.74	0.71
Total	**0.63**	**0.63**	**0.69**		**0.66**	**0.67**	**0.73**	

Global Cloud Fraction Comparison 2008

	Terra Ed2B	Aqua Ed1C	Terra Ed4	Aqua Ed4	CAL_80km
Day	0.60	0.61	0.63	0.63	0.69
Night	0.59	0.59	0.66	0.67	0.73

Cloud Mask Summary

- Daytime

    - picking up more low clouds over land and ocean
        - *cloud type most missed by Ed2*
        - *overall increase of 0.027 relative to Ed2*
        - *closer to CALIPSO results than Ed2*
    - Aqua picking up 0.03 fewer ice clouds over land
        - *reason not clear, switch from liquid to ice?, ratio overwrite?*
        - *0.000 change overall in Terra data*

- Nighttime

    - picking up more clouds over land and ocean
        - *mostly low, water, type most missed by Ed2*
        - *overall increase of 0.098 relative to Ed2, 0.026 loss in ice clouds*
        - *greatest increases in Arctic & Tropics, decrease over Antarctica*

- Total

    - 0.06 less than CALIPSO leaving out 80-km clouds
        - *difference is 0.06 less than Ed2*

Cloud Property Retrievals

- new Terra calibration for 0.65 & 3.8 μm

- rough ice crystal reflectance models

- ozone attenuation correction

- increased tau limit from 128 to 150

- new thickness and physical top parameterizations

- new parameters for Ed4

Cloud Heights

- New lapse rate introduced for boundary-layer clouds
    - seasonally, regionally variable
    - increased layer top to 780 hPa over ocean, interpolation to 680 hPa
                                    750 hPa over land, interpolation to 650 hPa
                                    765 hPa over coast, interpolation to 665 hPa

- CO_2 heights used when VISST too low

- rough models in VISST ice cloud retrieval yield different optical depths

- Cloud top physical height added and improved

Cloud Top Height km, Aqua 2008, Night Time, Land
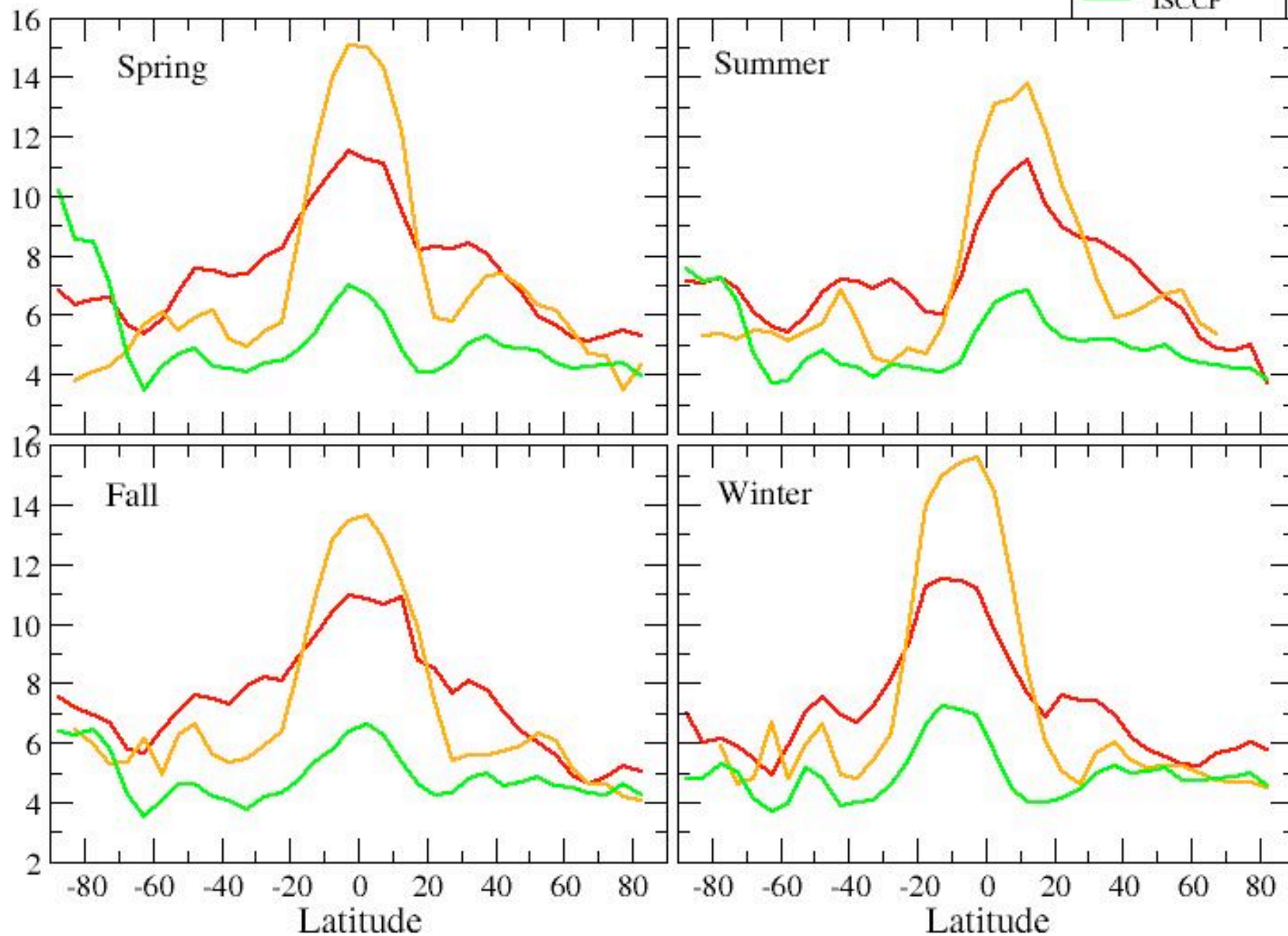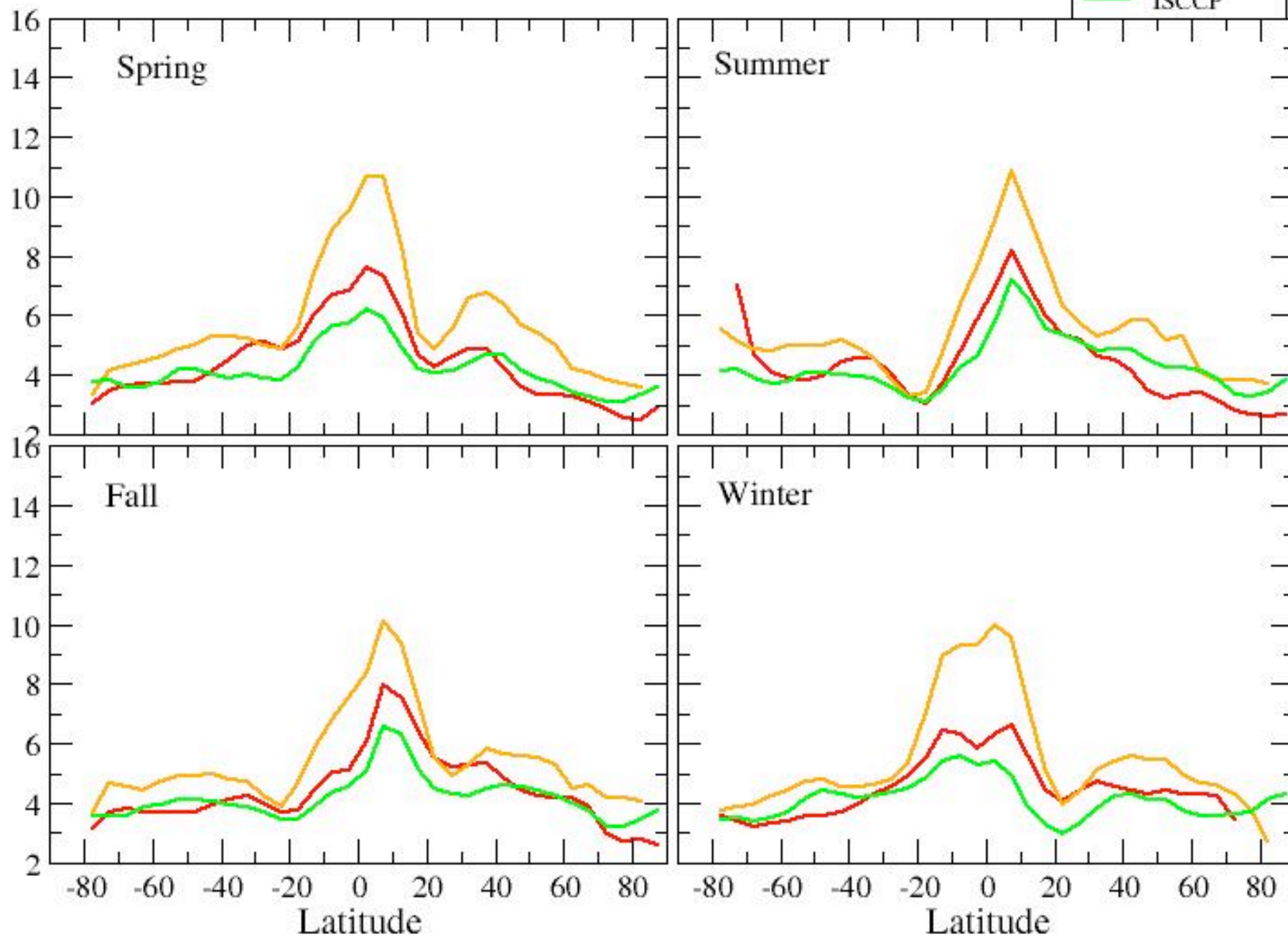
Cloud Top Height km, Aqua 2008, Day Time, Ocean
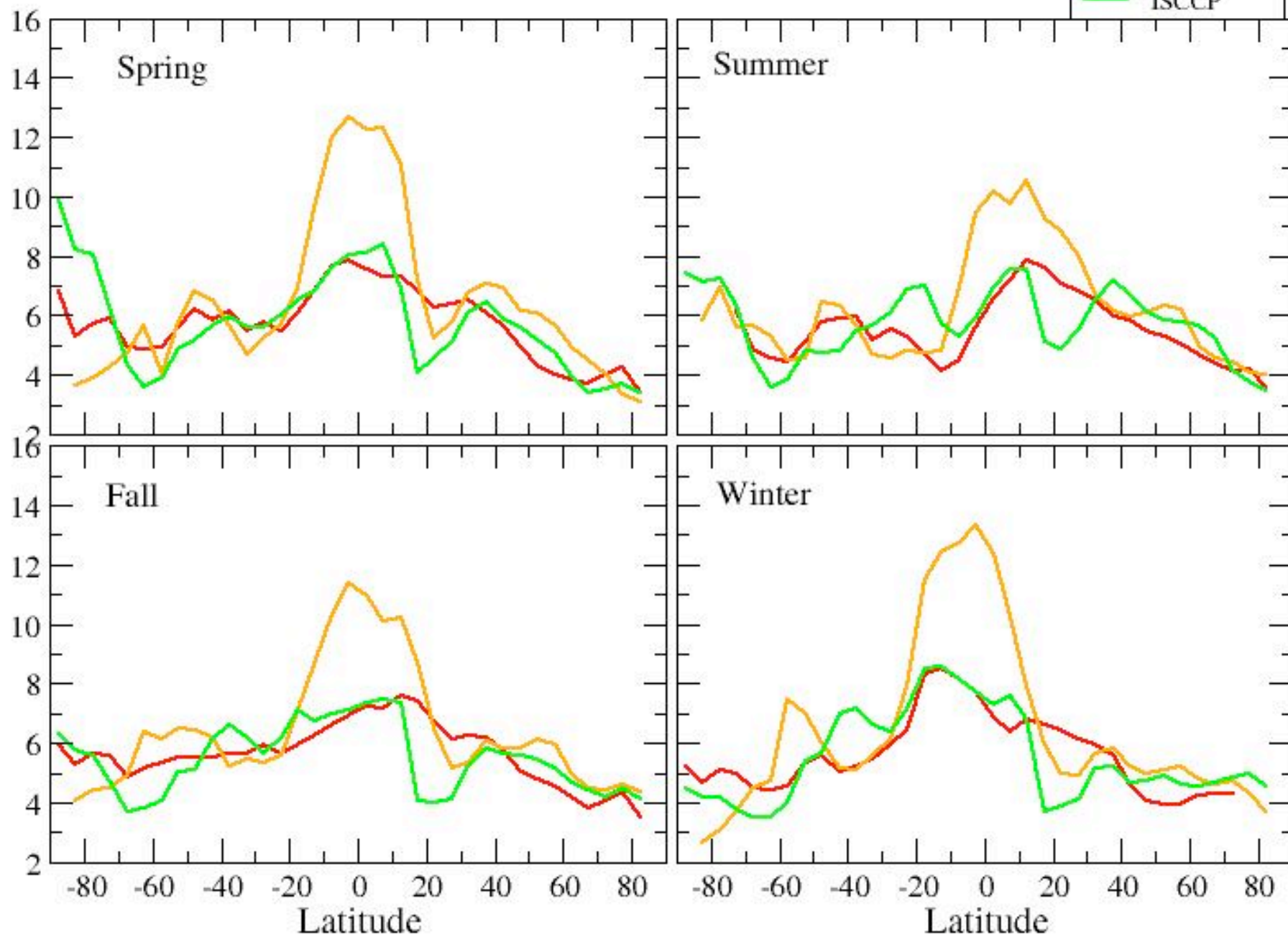
Cloud Top Height km, Aqua 2008, Day Time, Land

Cloud Top Height km, Aqua 2008, Day Time, Ocean
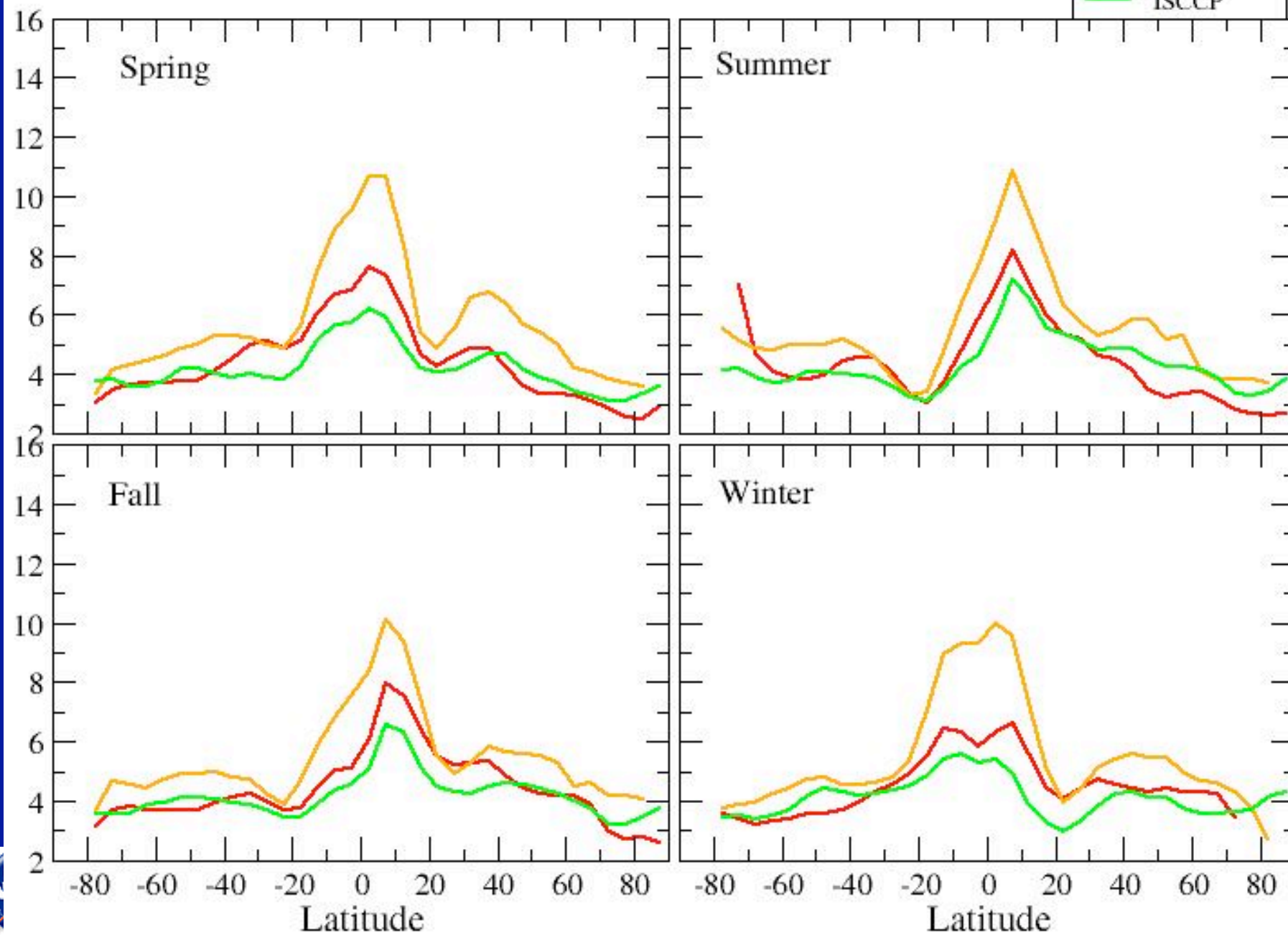
Cloud Height Changes from Ed2, Aqua
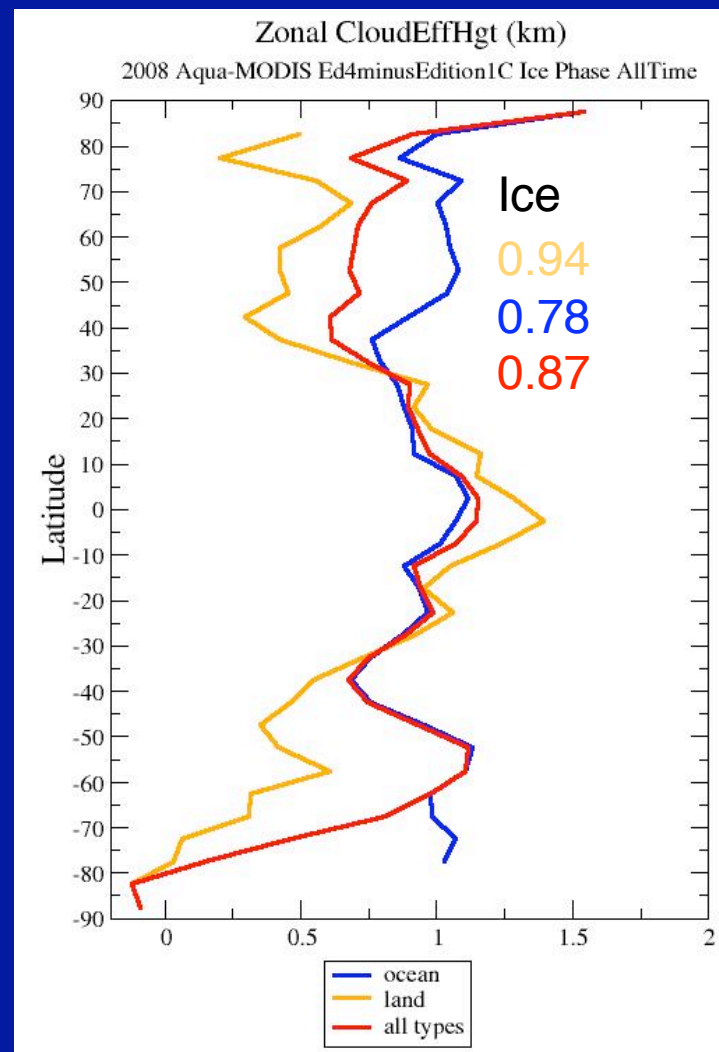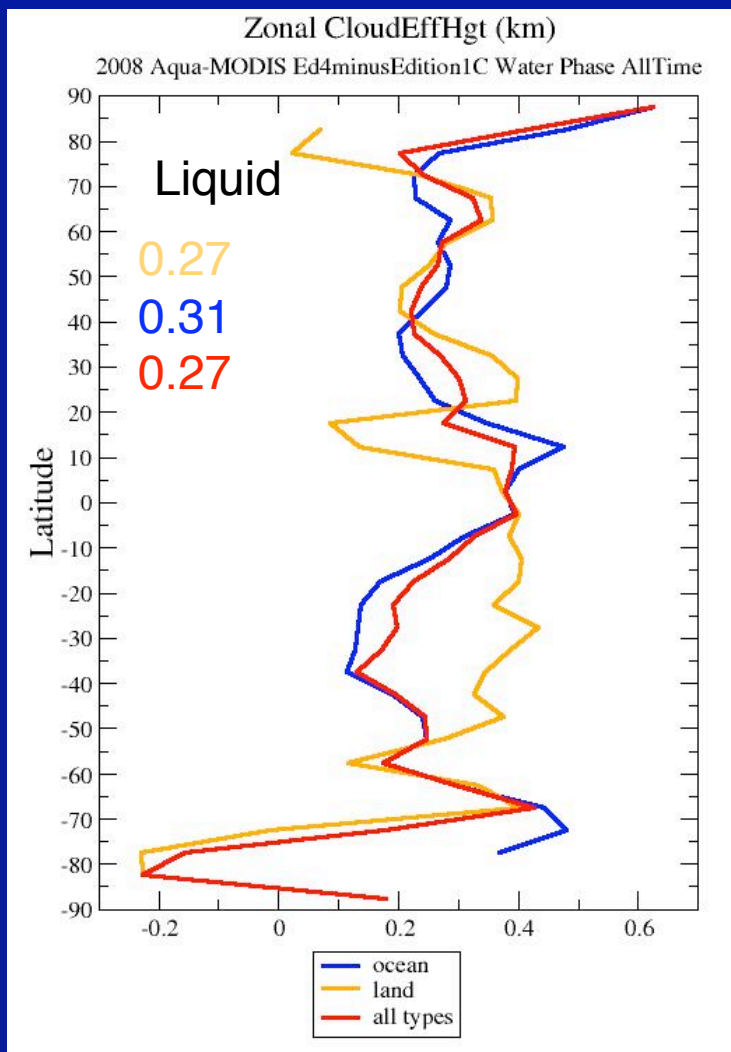
- Effective height changes all positive on average
- Terra same for ice clouds, near zero for water clouds
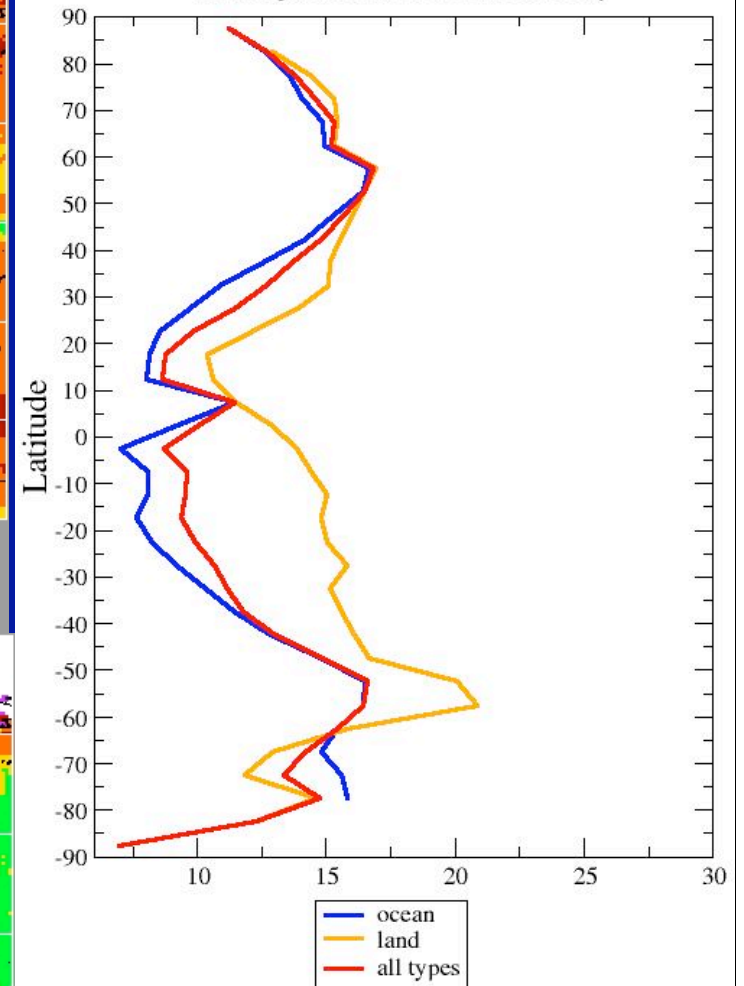- 0.2 km Ed2 Terra – Aqua difference in water height gone in Ed4

Cloud Optical Depth

Aqua 2008, Daytime
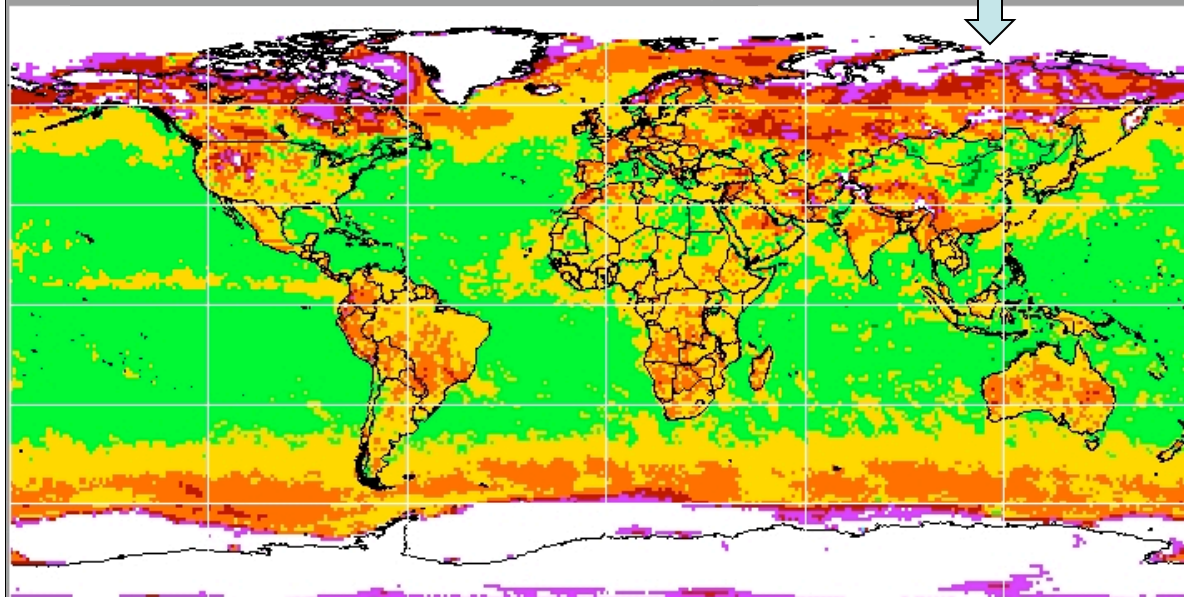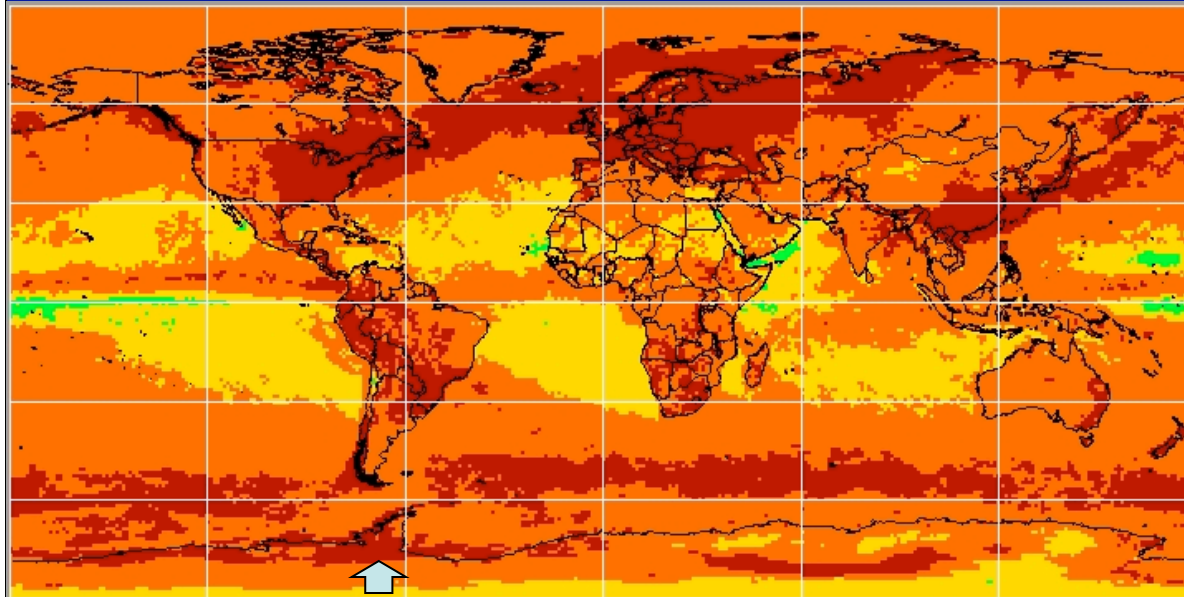
Ed4-Ed2, Daytime

Daytime Optical Depth Difference, Aqua Ed4 –Ed2
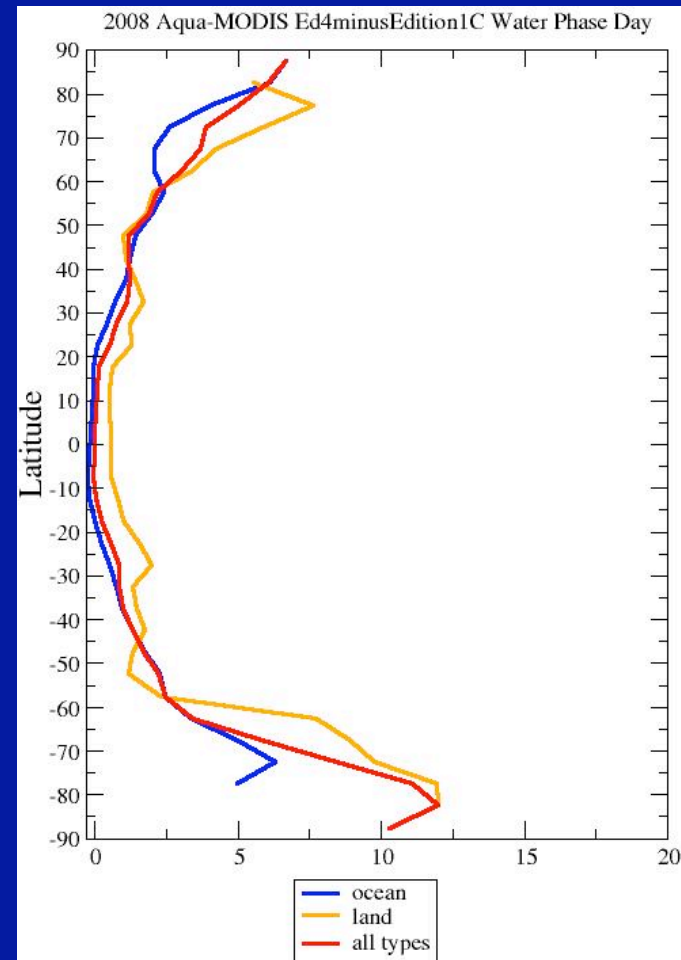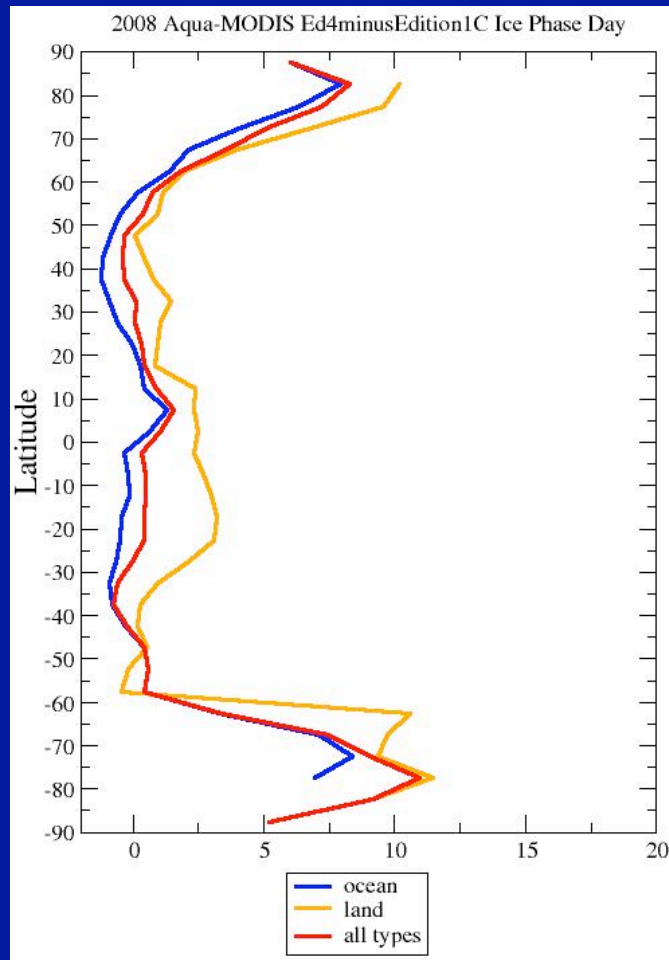
- Ice tau decreases in many ocean areas between 55°N and 45°S
    - *water tau decreases in areas between 20°N and 20°S*
    - *Terra has similar ice tau decreases in that zone*

- Large increases in polar cloud taus, Terra also
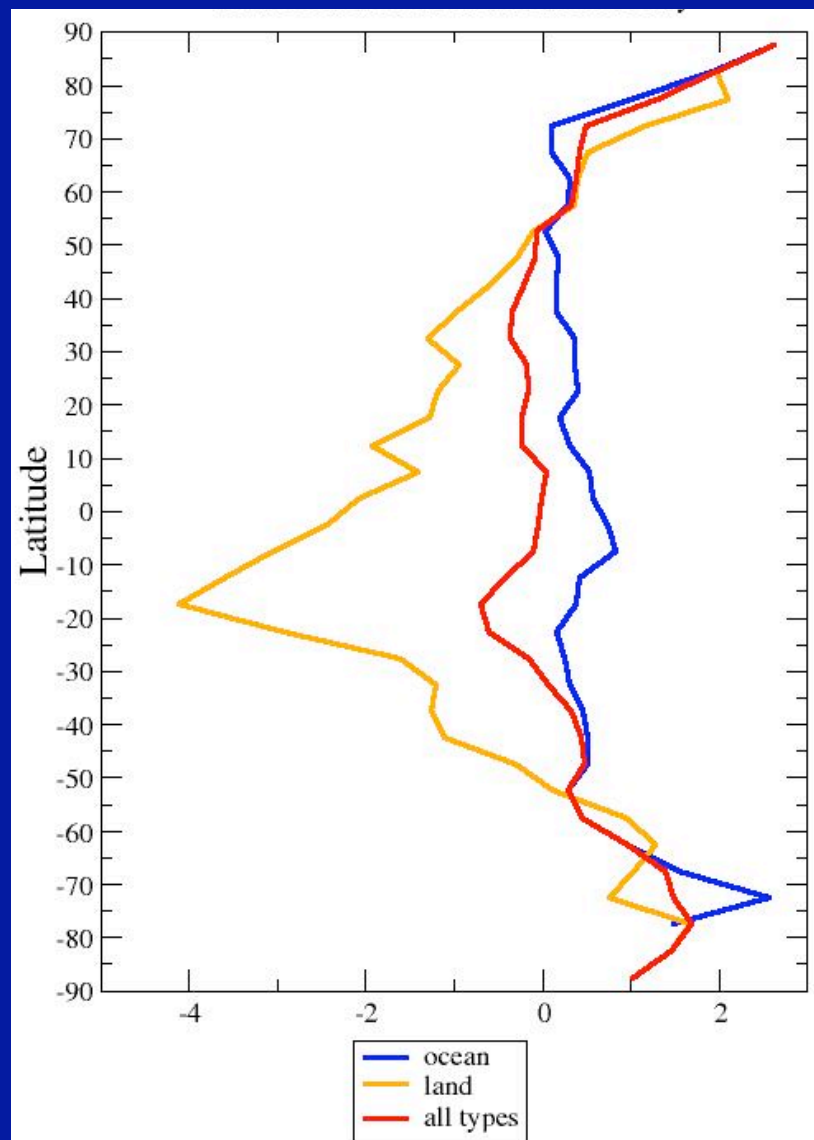
Daytime Optical Depth Differences, Ed4 –Ed2

Terra

Aqua

2008 Terra-MODIS Ed4minusEdition2B-QC Total Phase Day

2008 Aqua-MODIS Ed4minusEdition1C Total Phase Day
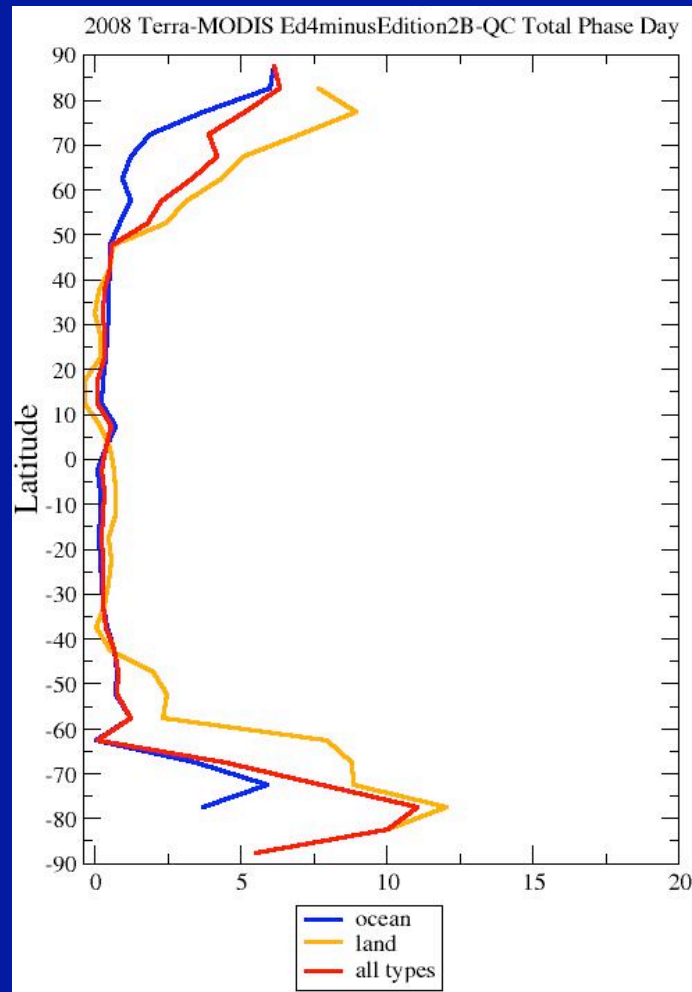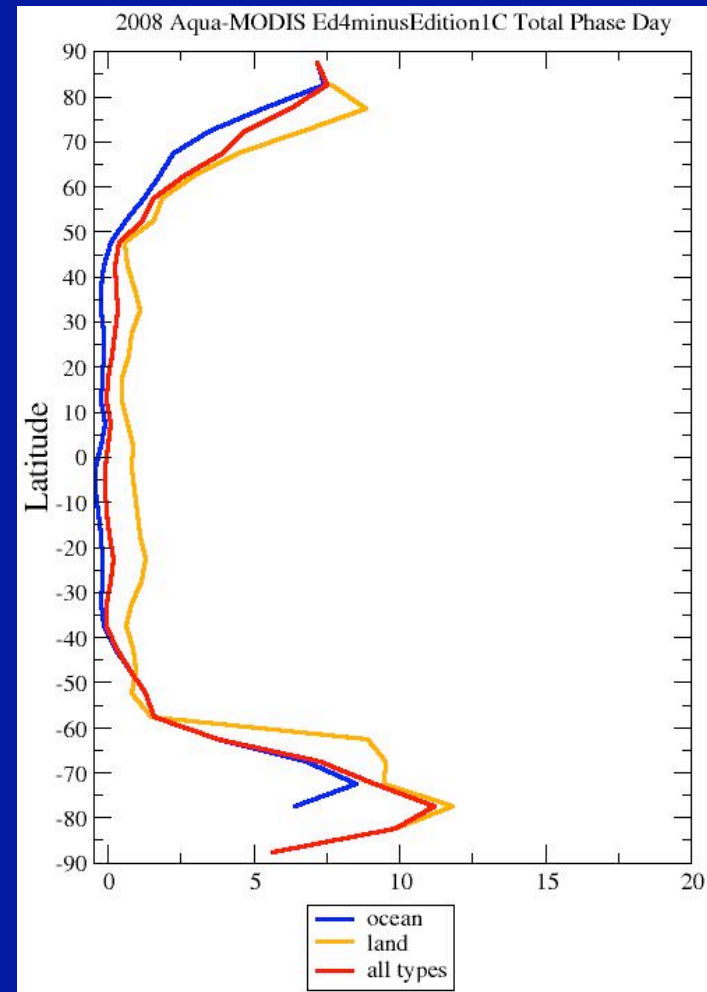
- Minimal change in non-polar regions
- Significant increase in polar regions: 1.24-μm replaced 1.6/2.1 μm

Ed4 Optical Depth Difference, Terra – Aqua, 2008

- Minimal difference over non-polar ocean, mostly positive
  - stratus thinning?

- Significant negative difference over non-polar land
  - convective development in afternoon

- Significant positive difference over polar regions
  - none expected
  - likely due to 1.24-*µ*m calibration
    - *Terra brighter than Aqua*
    - *affects clear brightness maps*

# 2008 Terra Cloud Droplet Effective Radius Difference (μm)
2008, Ed4 – Ed2
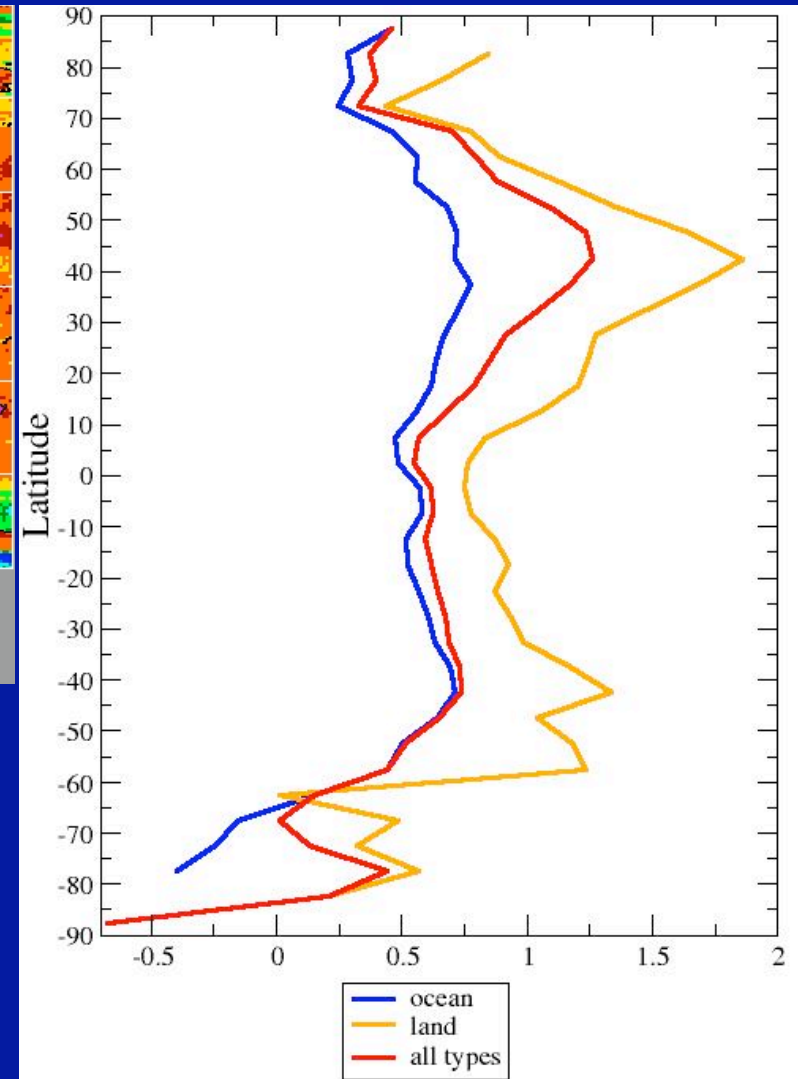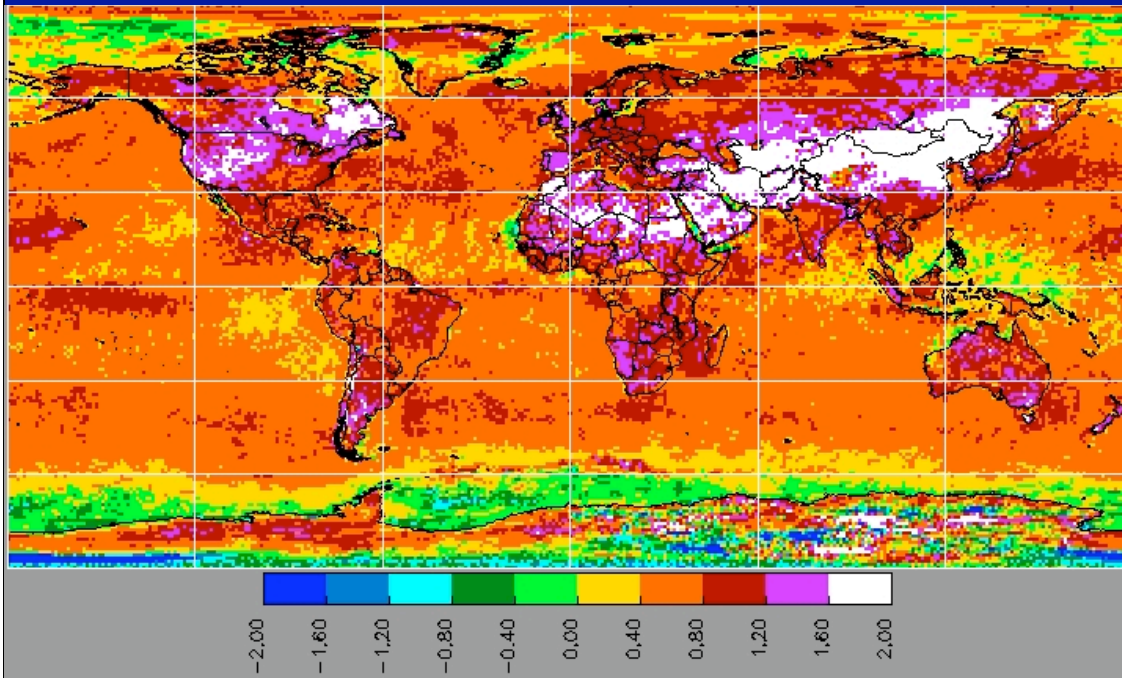
- 0.5 *μ*m increase over ocean, expected
- > 1 *μ*m increase over drier lands
  - *more thin low clouds*
  - *background influence?*
- decrease in some polar regions
  - *increased tau => smaller r_e*
- Aqua has net 0.0 change over water, 1 *μ*m over land
  - *decrease over Antarctica only*

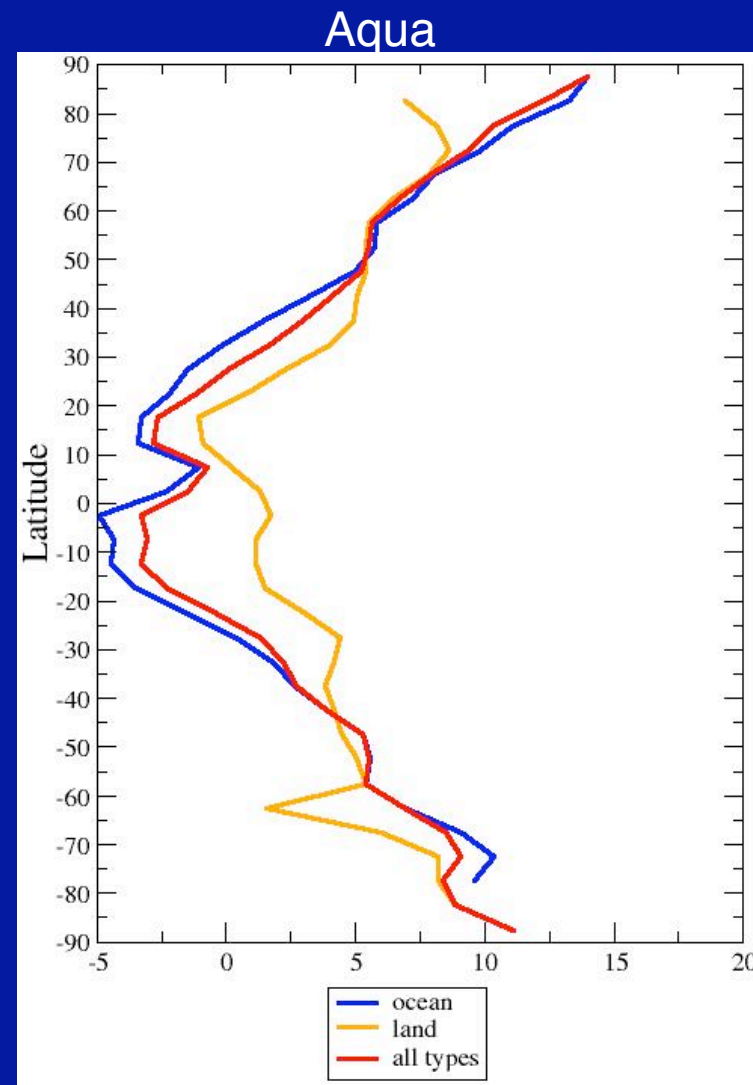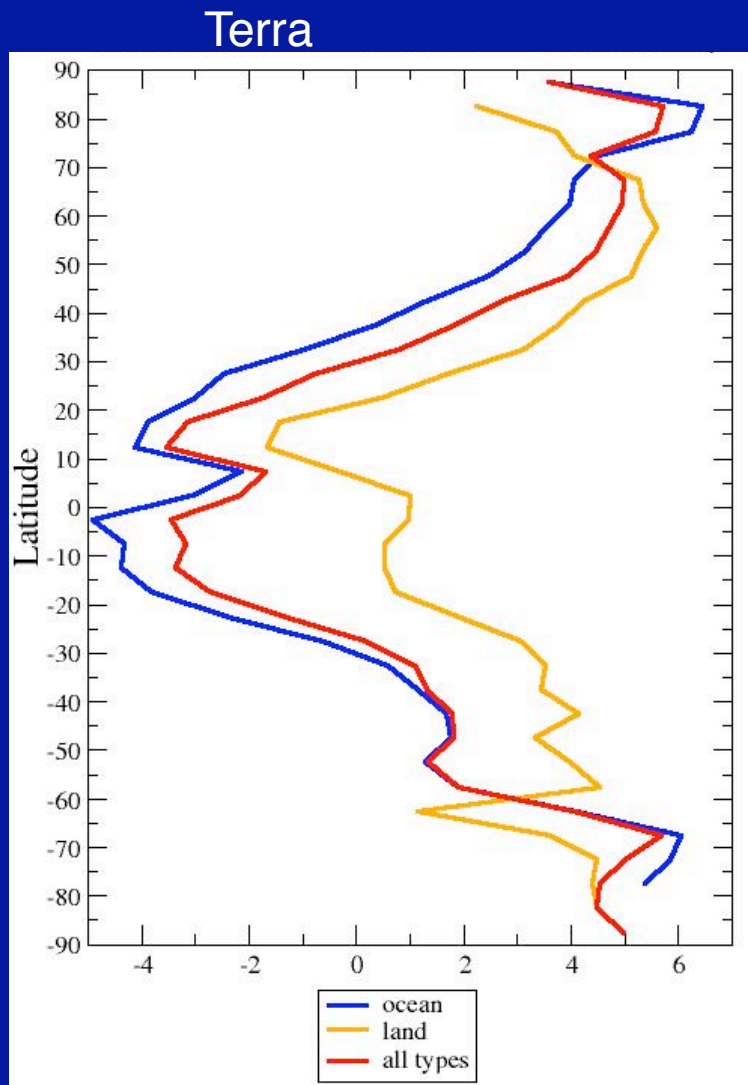## 2008 Cloud Droplet Effective Radius Difference (µm), Terra - Aqua
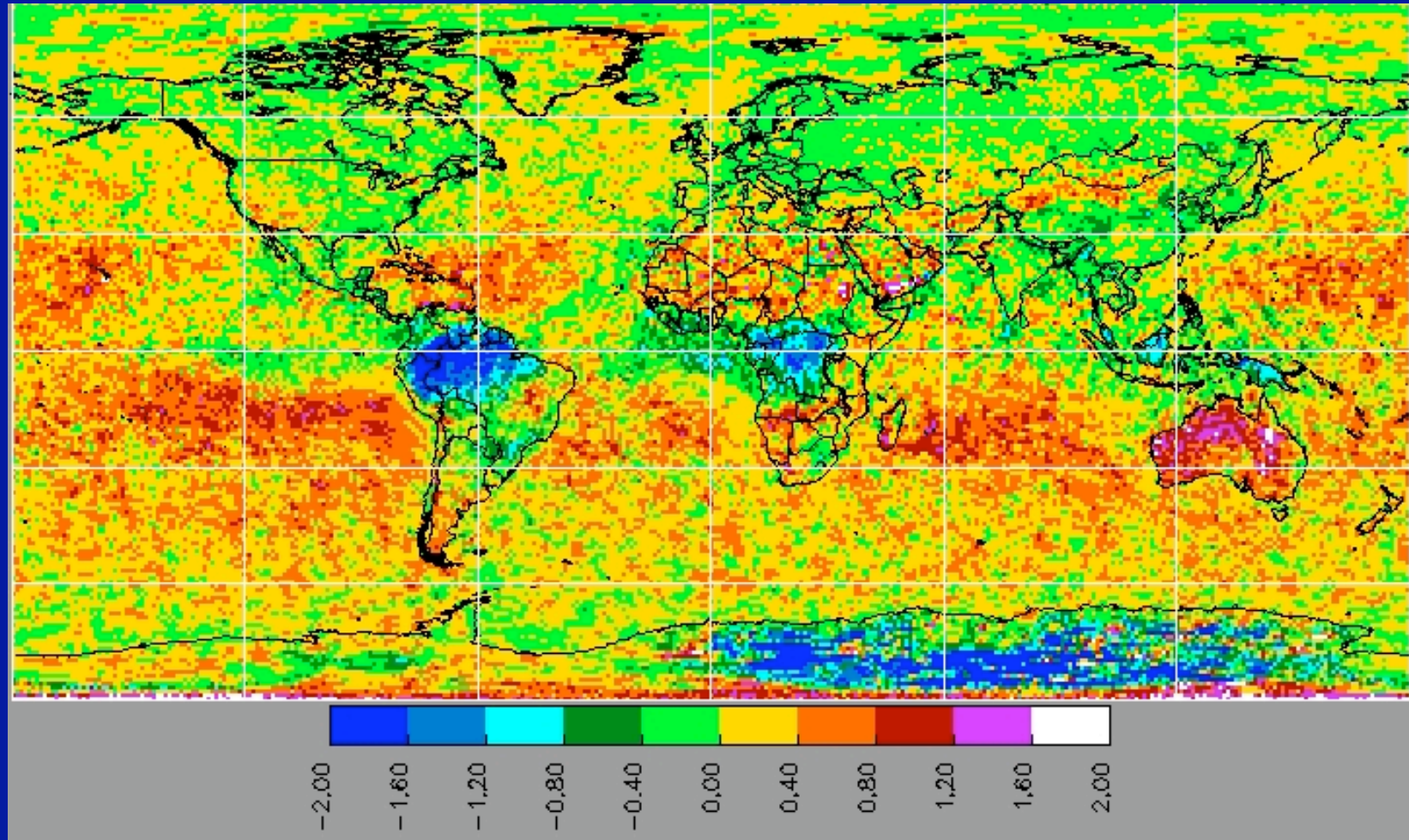
- r_e decreases during day over many ocean & desert areas
    - *thinning of stratus and altostratus?*

- r_e increases over land & marine deep convection areas
    - *ice cloud contamination? Thickening?*

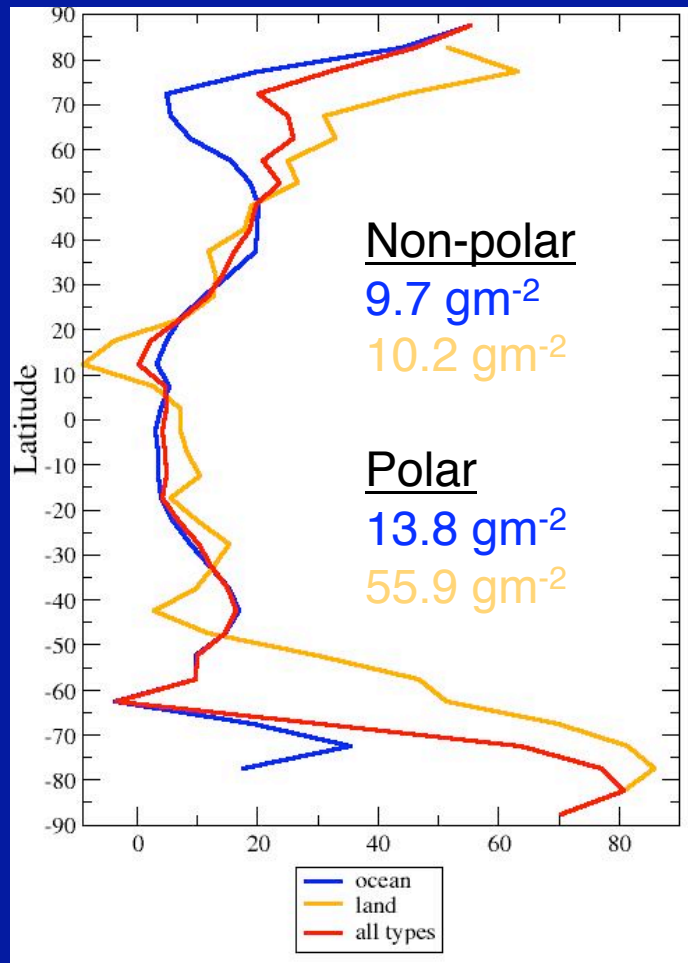# 2008 Zonal Average Ice Cloud Particle Size Differences, Ed-4 – Ed2

Terra

Aqua

- Increase in R_e for extratropical marine areas
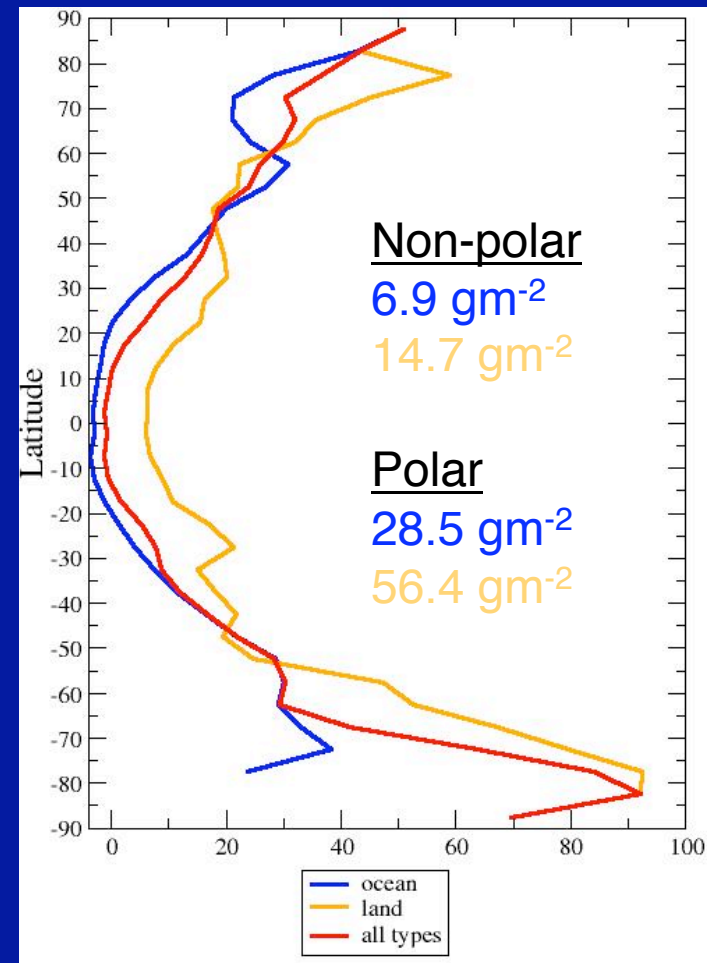- Increase over all land & snow, except for some desert

# 2008 Day Cloud Liquid Water Path Difference, Ed4 – Ed2

Terra

Aqua

Terra panel annotations:

Non-polar
9.7 gm^{-2}
10.2 gm^{-2}

Polar
13.8 gm^{-2}
55.9 gm^{-2}

Aqua panel annotations:

Non-polar
6.9 gm^{-2}
14.7 gm^{-2}

Polar
28.5 gm^{-2}
56.4 gm^{-2}

Legend (both panels): ocean, land, all types

- Increase nearly universal for Terra due to r_e increase
    - *drop in avg over small Cu areas*
- Except for marine Cu areas, increase everywhere for Aqua also

2008 Day Cloud Ice Water Path Difference, Ed4 – Ed2

Terra

Aqua

Non-polar
19 gm^{-2}
53 gm^{-2}

Polar
81 gm^{-2}
191 gm^{-2}

Non-polar
26 gm^{-2}
75 gm^{-2}
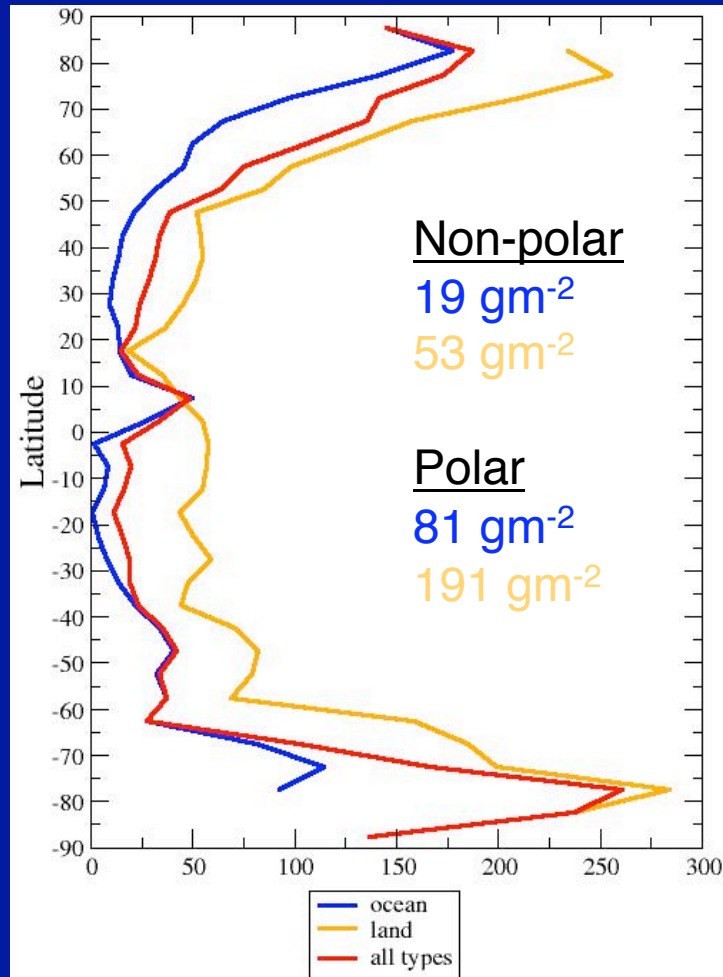
Polar
123 gm^{-2}
171 gm^{-2}
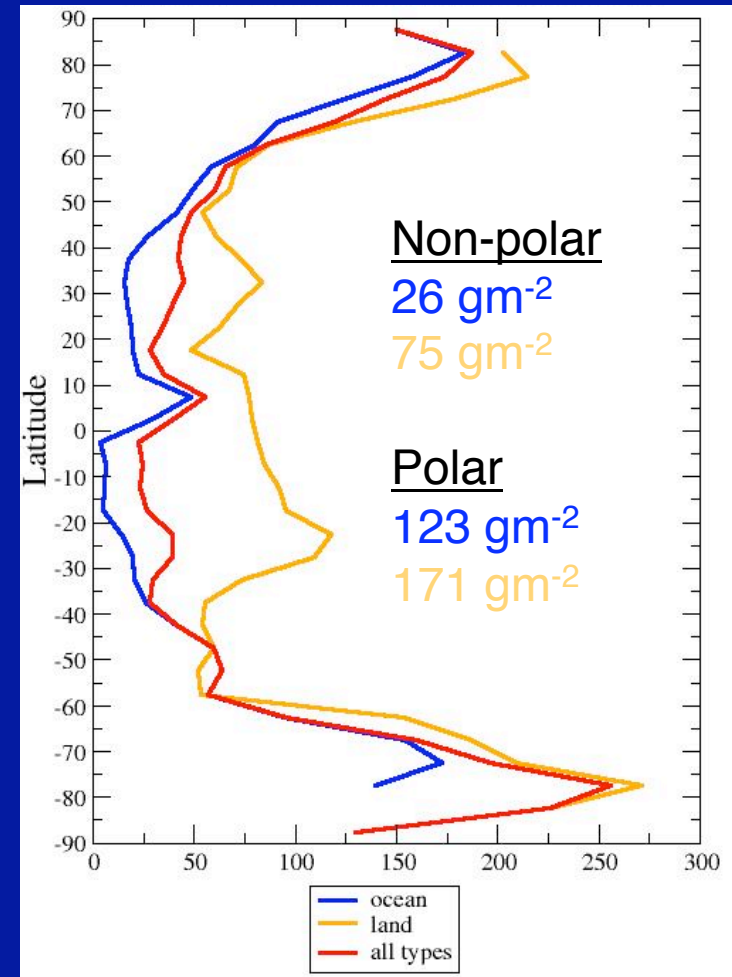
- Increase universal for both satellites due tau limit increase

- Greatest increase in polar areas: 1.24–μm increased tau, higher R_e

New Parameters for Ed4

- Cloud top height:

  - avg height 0.8 km above eff cloud height for ice clouds

  - avg height 0.03 km above eff height for water clouds

- r_e / R_e at 1.2 and 2.1 μm

  - only good for non-snow, tau > 2 or so

- multilayer cloud detection / retrieval

Droplet Effective Radius, Aqua, 30 July 2008

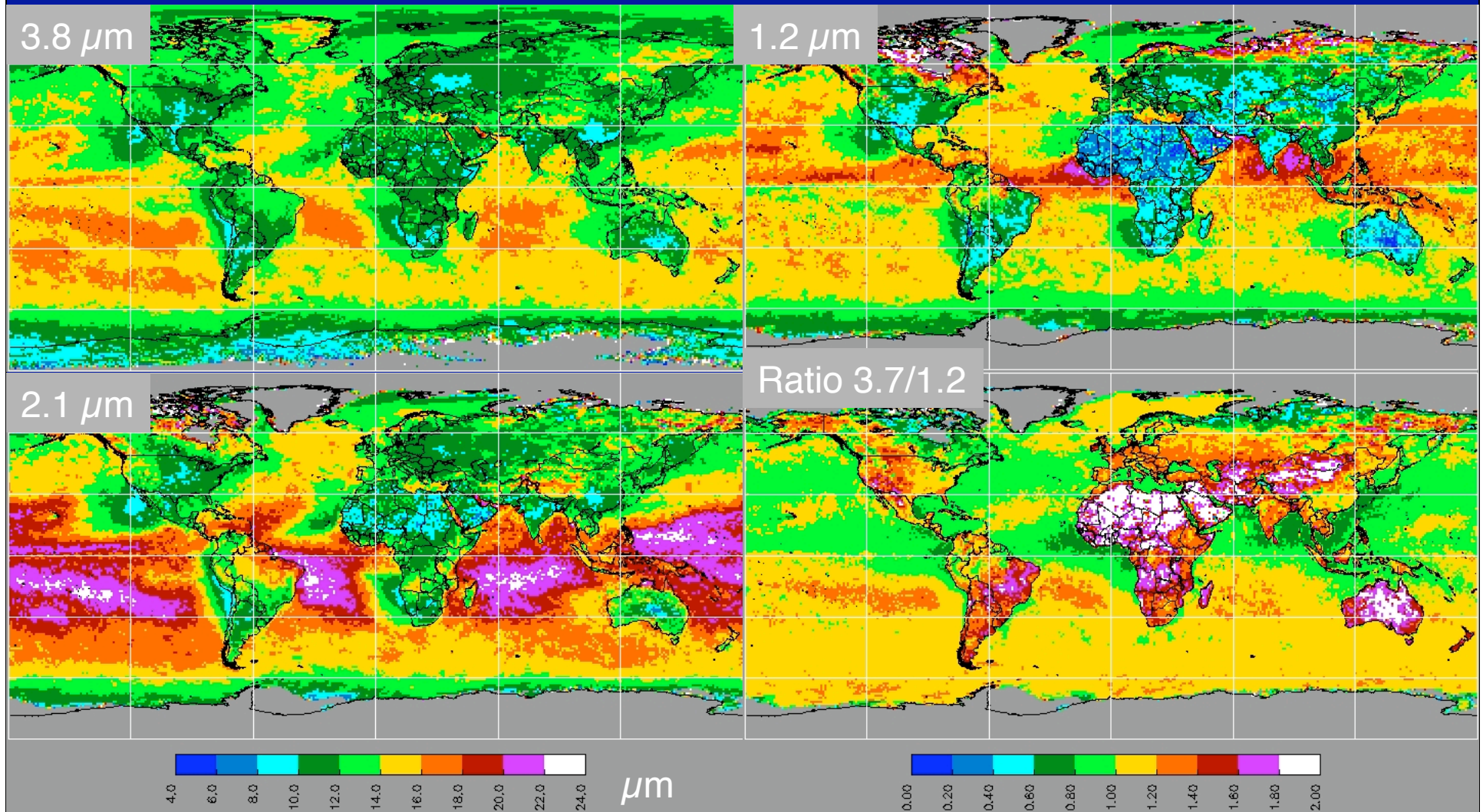RGB   3.7 μm   2.1 μm   1.24 μm
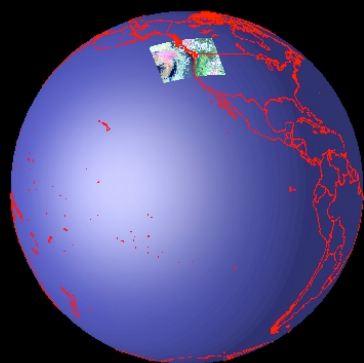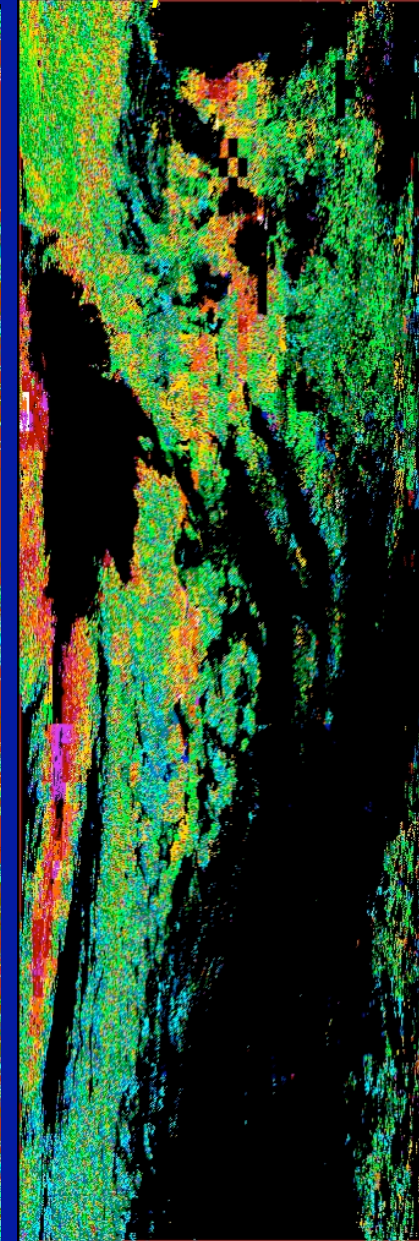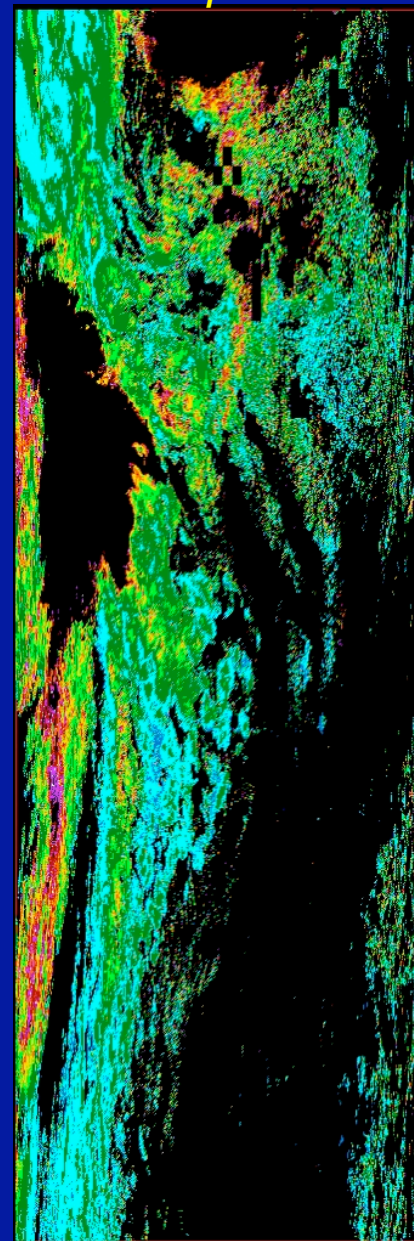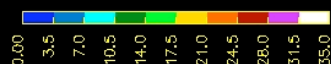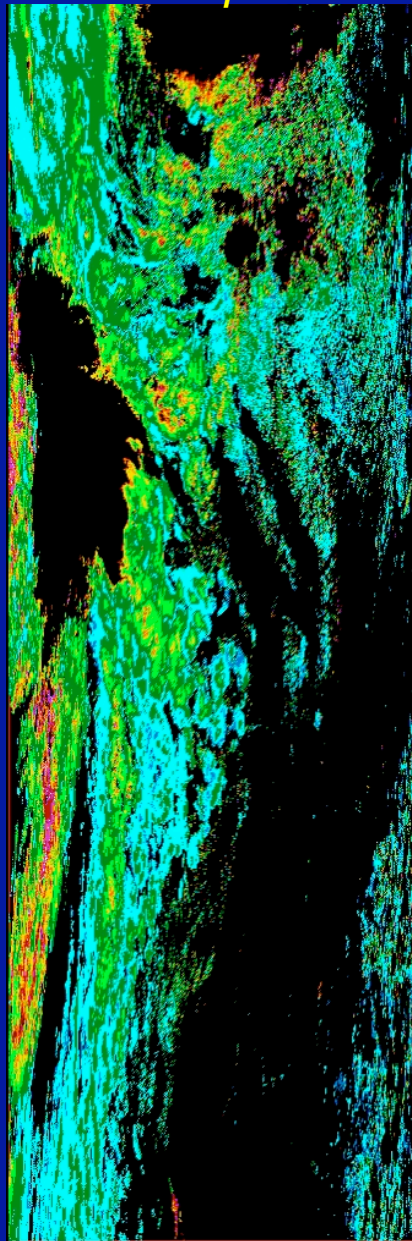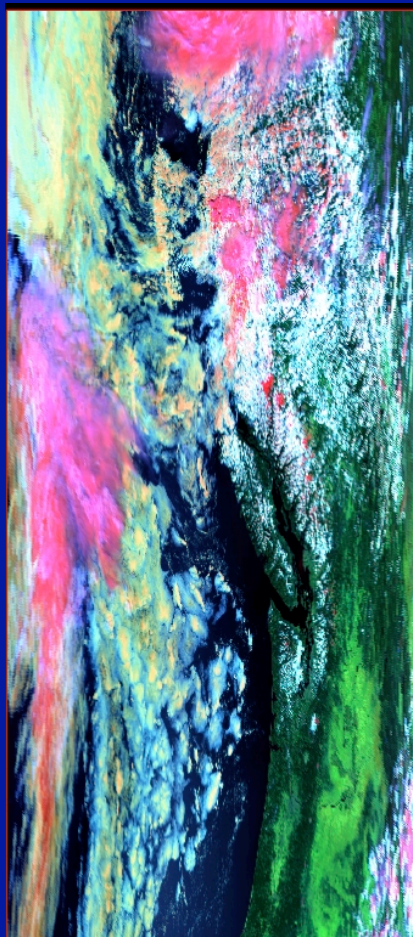
Droplet Effective Radius, Aqua, Spring 2008
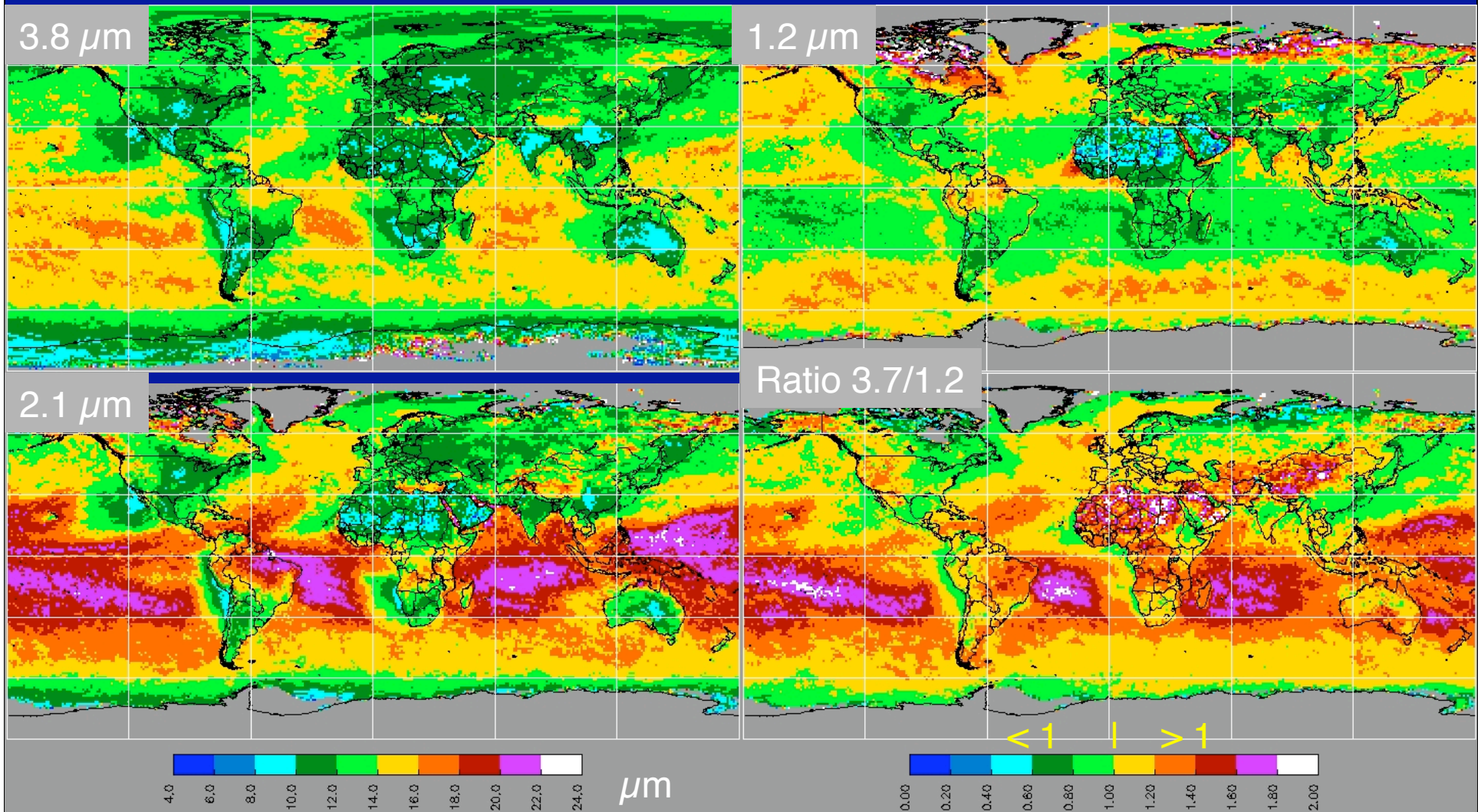
- Avg ratio only for tau > 2
- Ratio < 1 over many polluted areas?
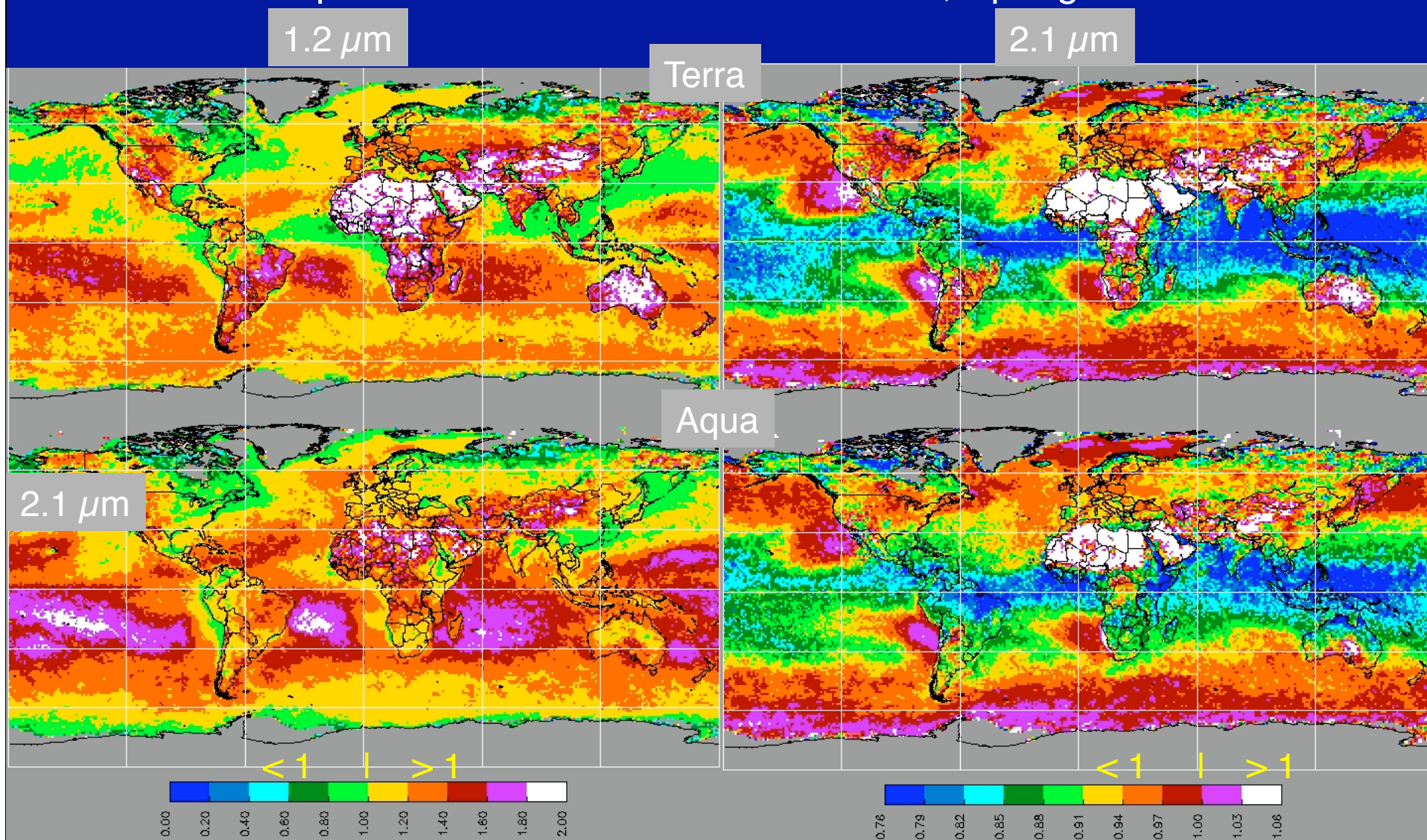
Droplet Effective Radius, Terra, Spring 2008

- Avg ratio only for tau > 2
- Ratio < 1 over most of northern ocean
- why is $r_e(1.2)$ larger than Aqua $r_e(1.2)$?

Droplet Effective Radius Ratios 3.7/X.X, Spring 2008

- Ratios mostly increase over ocean from morn to PM
- Ratio decrease over some land areas
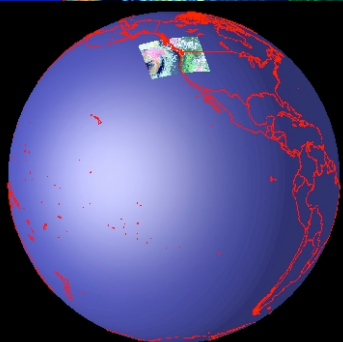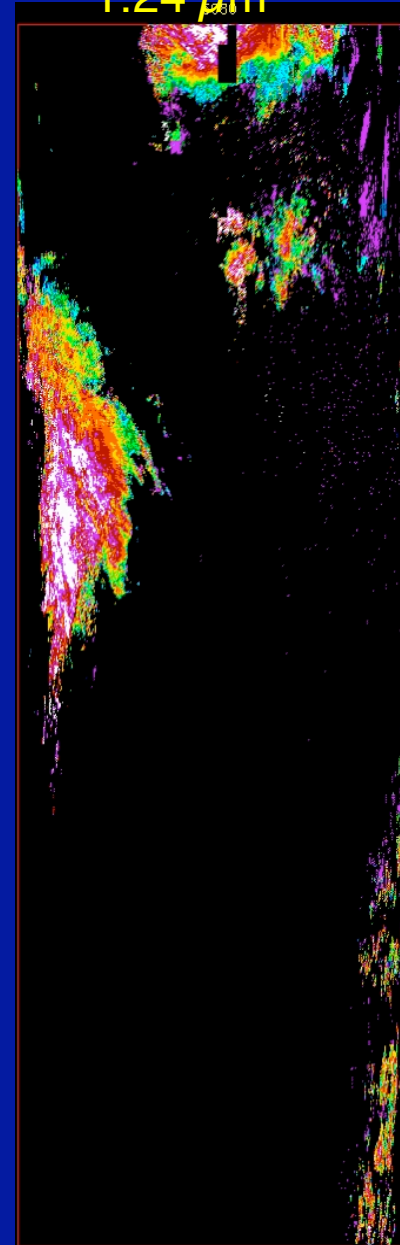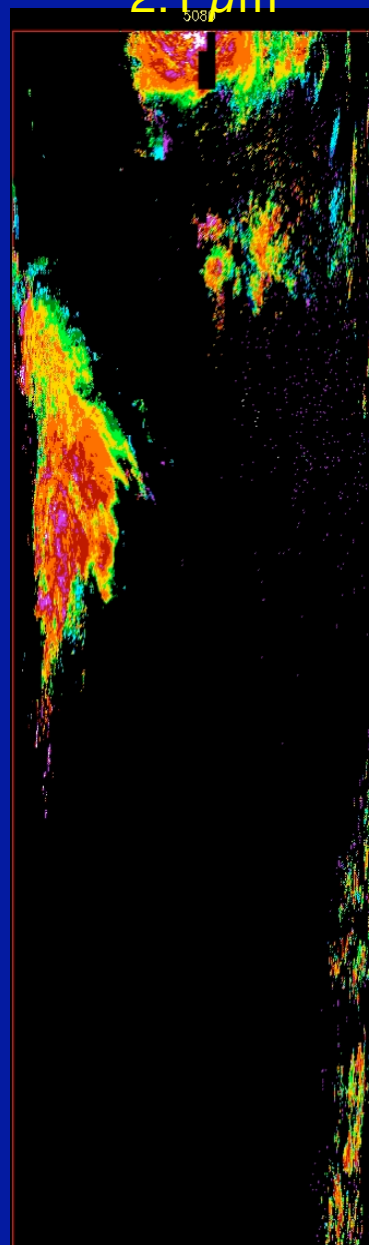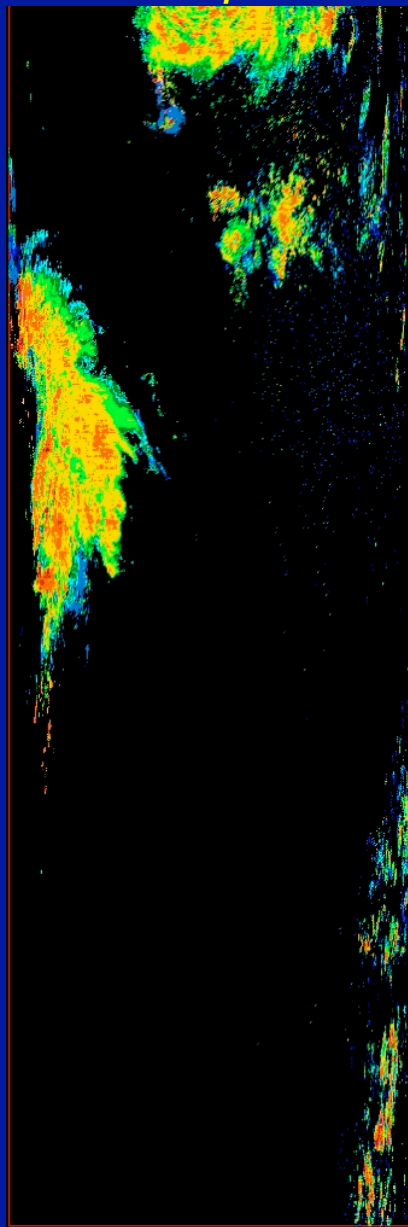- More drizzling over ocean in the morning?

Ice Crystal Effective Radius, Aqua, 30 July 2008

RGB 3.7 µm 2.1 µm 1.24 µm
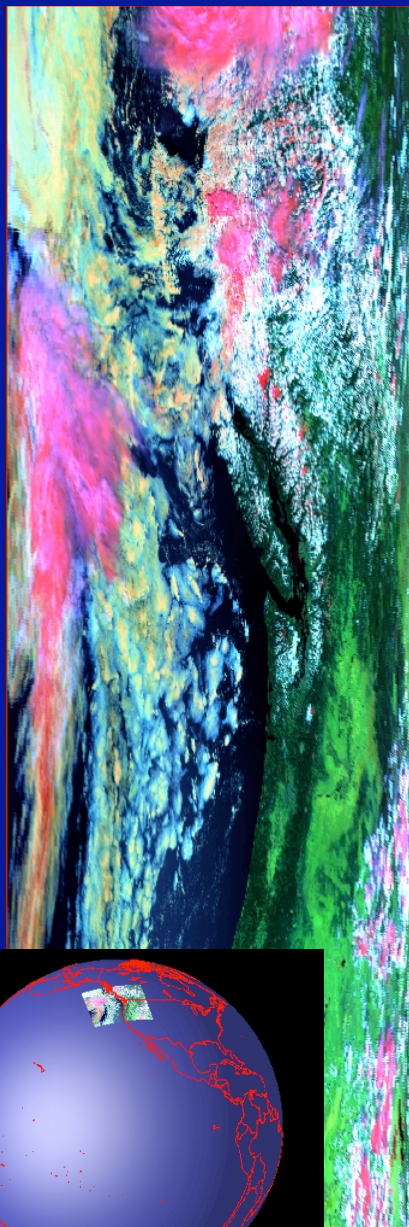
Ice Crystal Effective Radius, Aqua, Spring 2008, $\tau > 2$
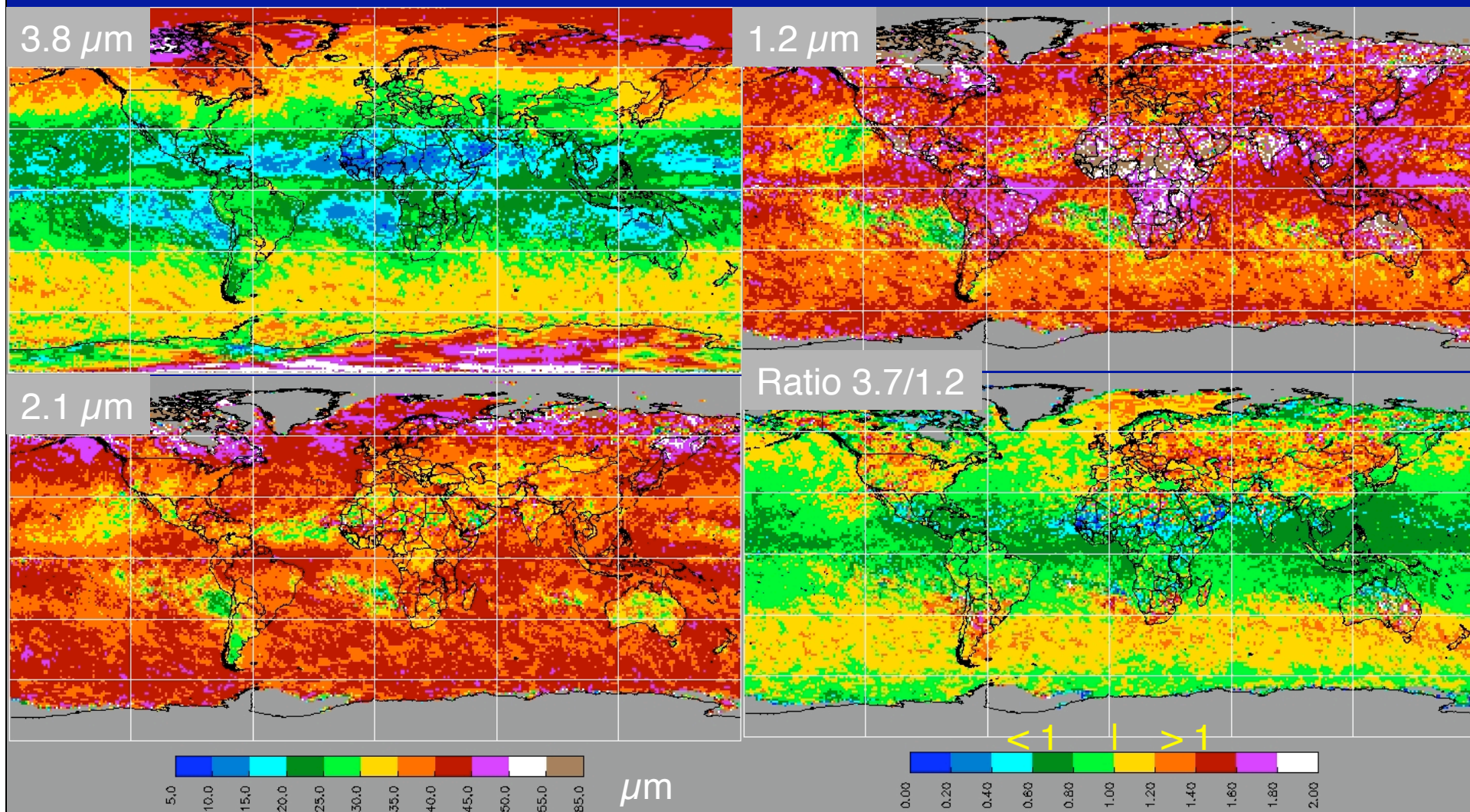
- 2.1 μm Re almost always > Re(3.7), usually < Re(1.24)
  - Need to remove pegged values
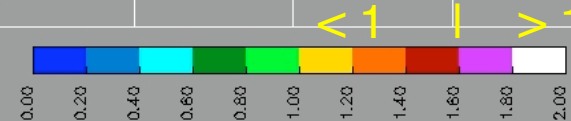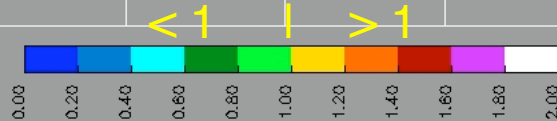- Terra-Aqua differences have some calibration errors
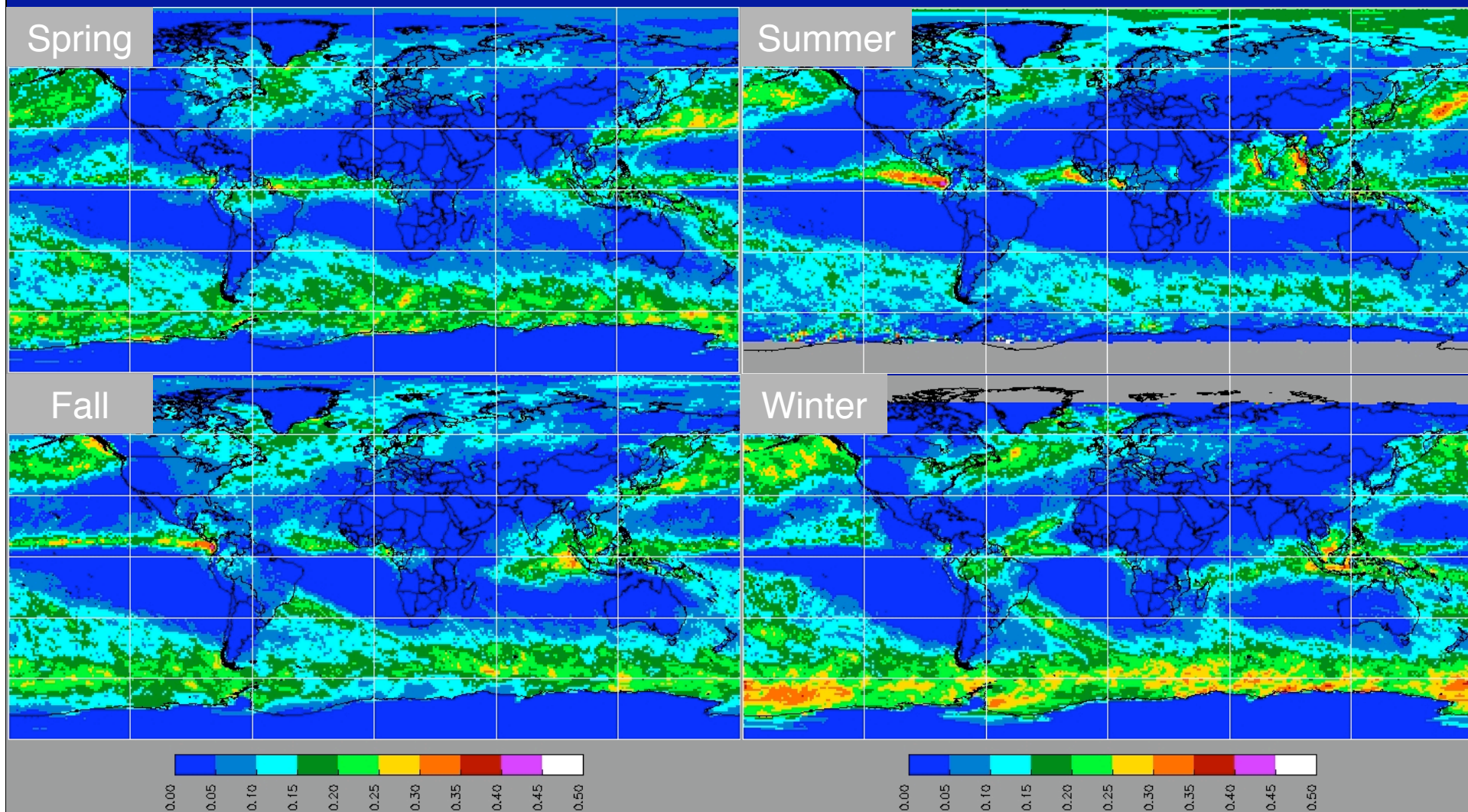
Ice Crystal Effective Radius Ratios 3.7/X.X, Spring 2008, $\tau > 2$

- Ratios mostly decrease over ocean from morn to PM for 1.24, not 2.1 μm
- 1.2 μm ratios exceed 1 over some land areas, even for Aqua
- Terra-Aqua differences have some calibration errors

Daytime Overlapped Clouds Using MCAT, Aqua, 2008

Spring

Summer

Fall

Winter

0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50

- Most detected overlap over water
    - *Storm tracks and convergence areas*
- 7.5 – 9.0% coverage, greatest in winter

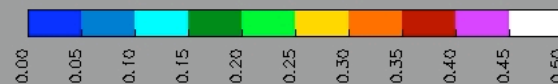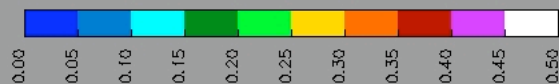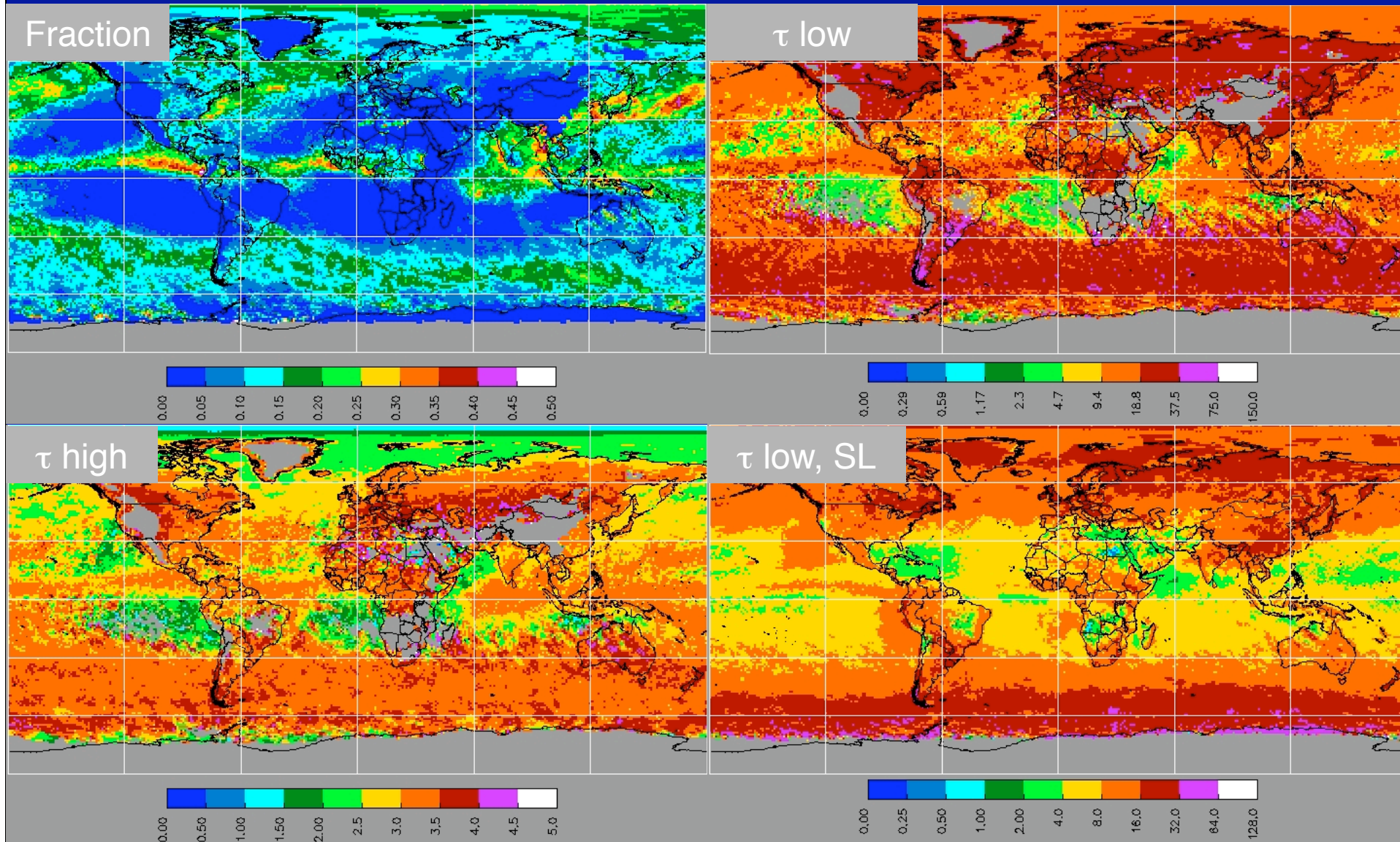Overlapped Clouds From Different Methods, Terra, Winter 2008

- Terra & Aqua yield comparable results with MCAT
- BTD methods detect more overlap
  - Pavolonis method yields most over land & ocean

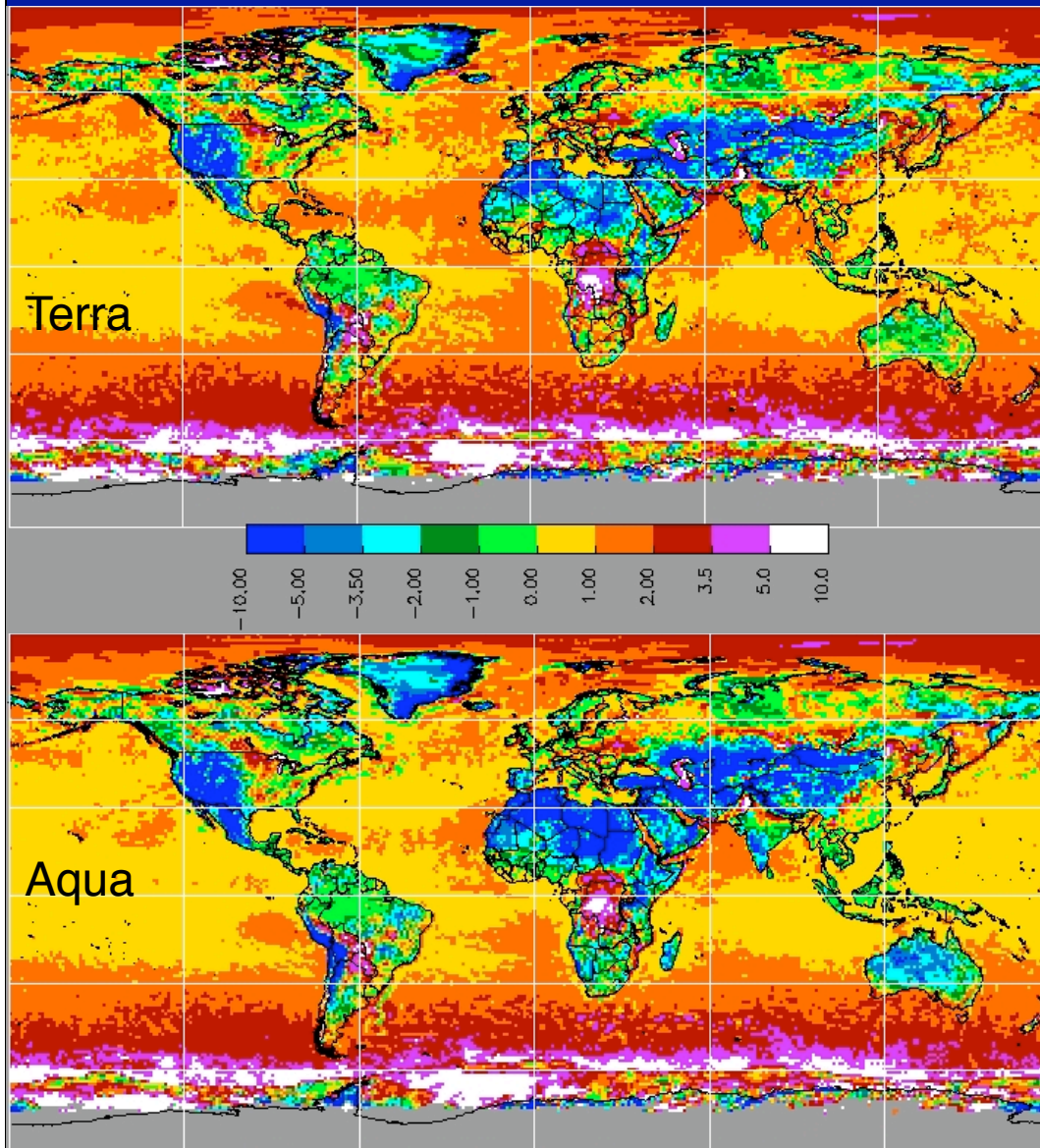# Overlapped Cloud Optical Depth, Terra, Summer 2008

- ML low clouds have optical depths comparable to SL water clouds
- ML upper ice cloud optical depths too high – coding error

Clear-sky 10.8-μm Temperature Differences, Summer 2008

T(GEOS-5) – T(obs)

• Good agreement over many ocean areas, a little overestimate
- *large bias in cloud-heavy areas*

• large negative differences over dry lands
- *larger in afternoon*
- *emissivity differences?*

• Reasonable agreement over vegetated land

Summary of Ed4 Clouds

- Delivered in February, not yet being processed

- Overall results look very good, but problems remain that need fixing
    - fast fixes

- Calibration
    - *1.24 and 2.1 µm have variations up to 5% between Aqua and Terra*
    - *affects cloud mask*
    - *affects snow albedos/ optical depth over snow*
    - *affects new particle size information*
- Multilayered clouds
    - *Upper cloud optical depths incorrectly calculated*
        - *easy fix*
- Pegged 1.24/2.1 Re/re
    - *prevents reliable statistical calculation*

- Ice cloud decreases over land: not sure of problem, 2 weeks?